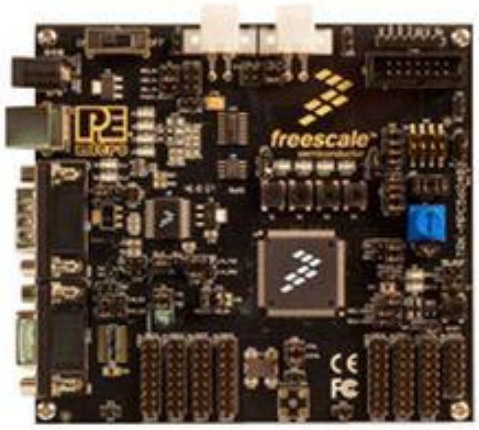
Presentation of MPC5604B MCU (Qorivva)



http://www.alexandre-boyer.fr

Alexandre Boyer
Patrick Tounsi

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This document aims at providing basic information for application development on the microcontroller MPC5604B. The content of the document is not exhaustive and does not detail every part of the microcontroller (MCU). Only the peripherals and functions which are required for the lab are presented.
Some library and code source examples are also provided to get familiar with the MCU programming. For more technical information about the component, please refer to the datasheet **Bolero512K_RM_Rev7_07_2010.pdf.** Links to the datasheet will be provided in this document.

Remark: sometimes, the register names given in the datasheet do not match with those provided by the MCU library **MPC5604B_M27V.h**. Don't hesitate to verify the right name in the library.

You can also refer to the MPC5600 cookbook document from Freescale, **AN2865 - MPC5600 cookbook.pdf**, which provides several software examples to start using MPC5600 MCU family.

Your applications will be developed on evaluation boards TRK-MPC5604. Please refer to the user manual **TRKMPC5604BEVBUM.pdf** for more detail about the test board, and to the schematic **TRK_MPC5604B_Rev_B_Schematic_Layout.pdf**.

I - Presentation of the MCU MPC5604B

MPC5604B is a MCU developed by Freescale Semiconductor and belongs to the family MPC560x, also called Qorivva. It is a 32 bit MCU dedicated to automotive body applications designed in CMOS 90nm technology. Its core is based on a Power Architecture ® and a e200z0 CPU. The version used in the Lab is MPC5604BxLQ, which is mounted in a LQFP 144 package.
Its main characteristics are:

- Up to 512 KB of Flash memory for code, and 64 KB of Flash memory for data
- Up to 32 KB of SRAM memory
- Core frequency up to 64 MHz, based on a frequency modulated PLL (FM PLL)
- An interrupt controller (INTC) with 148 selectable priority interrupt vectors, including 16 external interrupt sources
- 36 channels for 10-bit analog-to-digital converters (ADC)
- Up to 3 serial peripheral interface (DSPI) modules, 4 serial communication interface (LINFlex), 6 CAN modules (FlexCAN)
- Up to 123 configurable general purpose input-output (I/O)
- Up to 6 periodic interrupt timers (PIT) with 32-bit counter resolution
- Device testing based on JTAG bus (IEEE 1149.1)

Fig. 1 presents the block diagram of the MCU.

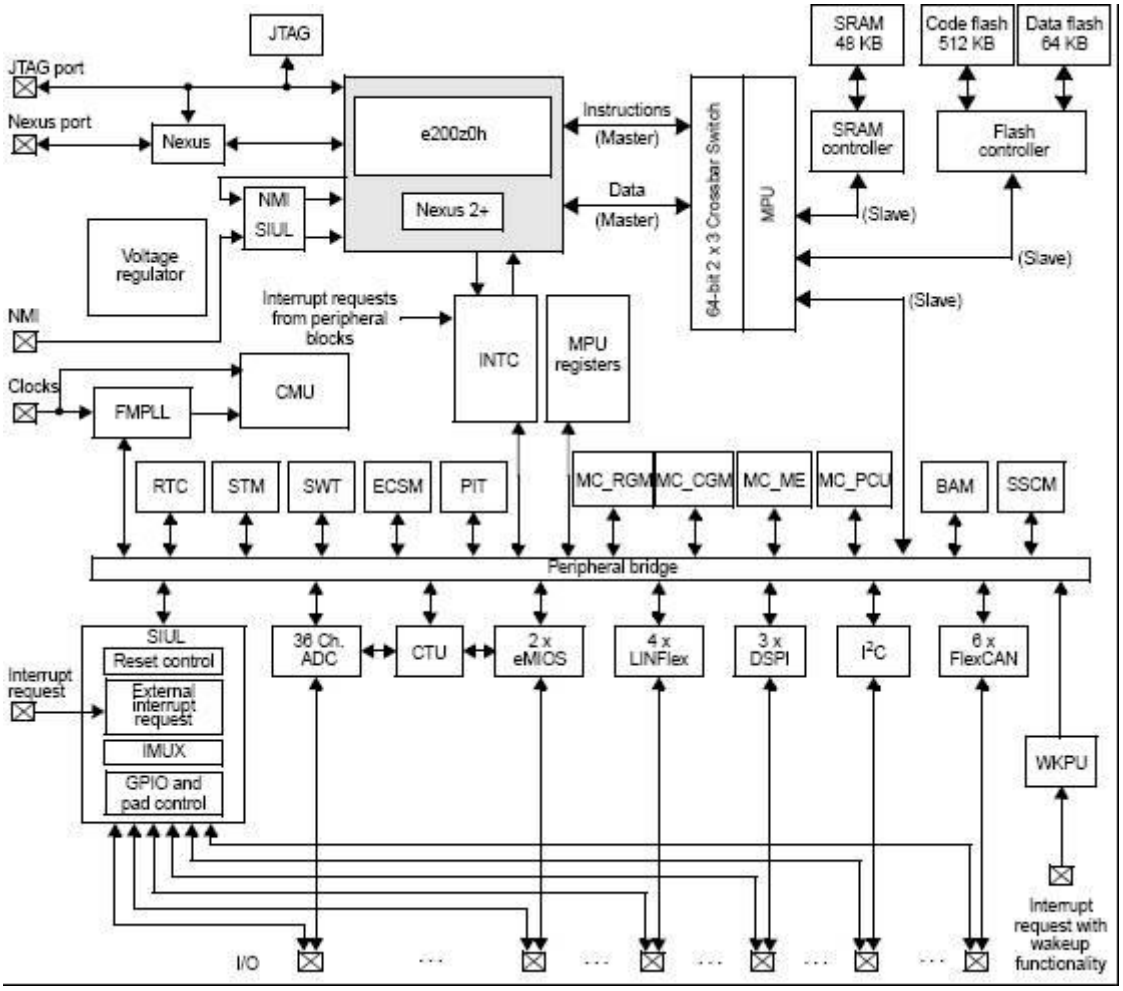


Figure 1 - Block diagram of MPC5604B (Bolero512K_RM_Rev7_07_2010.pdf - p. 32)

Legend:

ADC	Analog-to-Digital Converter
BAM	Boot Assist Module
FlexCAN	Controller Area Network
CMU	Clock Monitor Unit
CTU	Cross Triggering Unit
DSPI	Deserial Serial Peripheral Interface
eDMA	Enhanced Direct Memory Access
eMIOS	Enhanced Modular Input Output System
FMPLL	Frequency-Modulated Phase-Locked Loop
I²C	Inter-Integrated Circuit Bus
IMUX	Internal Multiplexer
INTC	Interrupt Controller
JTAG	JTAG controller
LINFlex	Serial Communication Interface (LIN support)
ECSM	Error Correction Status Module
MC_CGM	Clock Generation Module
MC_ME	Mode Entry Module
MC_PCU	Power Control Unit
MC_RGM	Reset Generation Module
MPU	Memory Protection Unit
Nexus	Nexus Development Interface (NDI) Level
NMI	Non-Maskable Interrupt
PIT	Periodic Interrupt Timer
RTC	Real-Time Clock
SIUL	System Integration Unit Lite
SRAM	Static Random-Access Memory
SSCM	System Status Configuration Module
STM	System Timer Module
SWT	Software Watchdog Timer
WKPU	Wakeup Unit

II - MPC5604B programming main steps

This part aims at giving the main steps for the programming of the MCU. You are not forced to follow this sequence, it intends only to help you to start with programming.

- Initialization of system clock and modes for system and peripherals (see Chapters 3 and 4 for clock generation, Chapter 5 for mode entry module MC_ME).
  The operation mode must be defined at initialization for every peripheral. Enter in RUNx (x = 0 to 3) mode (see Chapter 5 for mode entry module MC_ME)

- Configure input-output pads (direction, alternate function activation, output drive, pull-up, pull-down, filtering) (see chapter 8 for System Integration Unit Lite module SIUL)
- Configure peripherals (clock, interrupt enable, parameters, energy mode…)
- Installation of INTC interrupt handlers
- Enable maskable interrupt requests
- Main program

The register names can be found in the MPC5604B datasheet, but the given names can differ from the actual name defined in the MCU library. Refer to Refer to the header file MPC5604B_0M27V_0100.h (normally included in your projects) to find the correct names of registers and bits.

III - Clock generation description

Refer to Chapter 3 – Clock description for more details about the clock architecture and Chapter 4 – Clock generation module (MC_CGM) for more details about the internal clock generation. Only the configuration of FXOSC and FMPLL are presented in this document. The activation and selection of clock sources for the system clock are managed by the mode entry MC_ME module.

1. Clock architecture

The system clock (sys_clk) can be built from three selectable sources:

- Fast external quartz oscillator (FXOSC), 4 – 16 MHz
- Fast internal RC oscillator (FIRC), 16 MHz
- Frequency modulated phase locked loop (FMPLL), synchronized for a 4 to 16 MHz clock reference. It can deliver a clock frequency up to 64 MHz

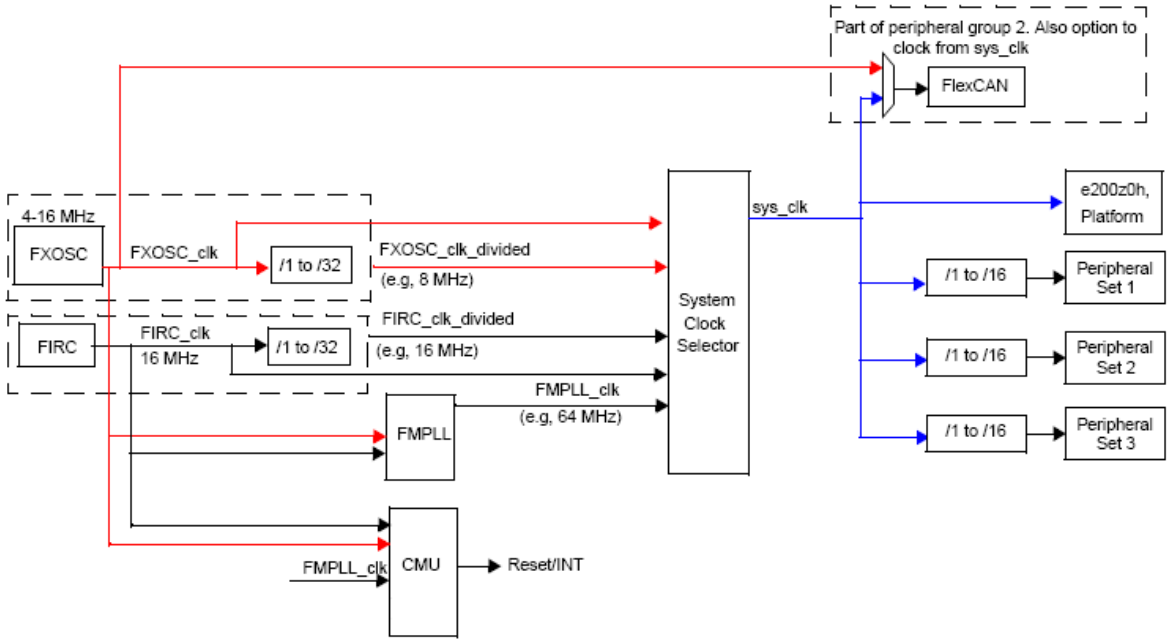
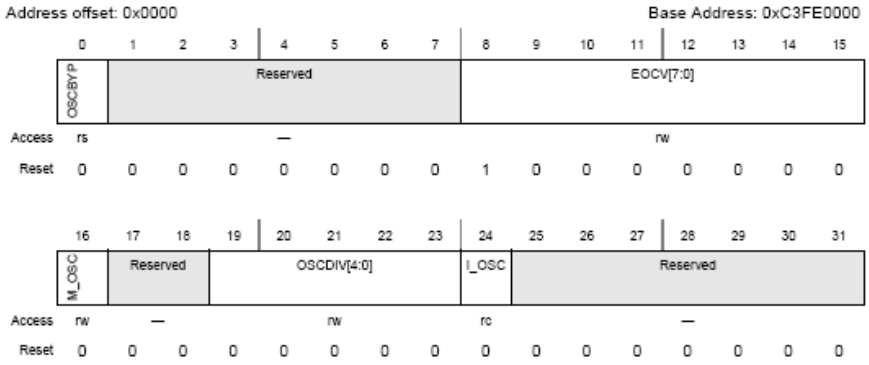


Figure 2 – Clock architecture (Bolero512K_RM_Rev7_07_2010.pdf - p. 70 – Fig. 3-1)

Except FMPLL, every clock source can be divided from 1 to 32 before sys_clk generation. Two additional low power oscillators are provided but are not detailed in this document. Fig. 2 presents the simplified clock architecture of the MCU. The system clock serves as reference for peripherals. Peripheral clock can be gated for energy saving purpose (refer to peripheral chapter to identify related registers).
The pin PA[0] proposes as alternate function CLKOUT, for the external observation of the system clock. The bit EN in the register OC_EN is set to enable the output clock (see p 104). The frequency of the output clock can be divided through the content of the register OCDS_SC.
The quality of clock sources is checked by the Clock Monitor Unit (CMU). This module can detect loss of clock integrity and switch to a SAFE mode in case of clock failure interrupt. It can also be used as frequency meter. Refer to Chapter 3.8 for more information.

2. Fast external oscillator (FXOSC)

Refer to Chapter 3.3 for more information about FXOSC. This oscillator uses a 4 – 16 MHz external oscillator circuit. It can provide a clock source for the system clock and an input for the FMPLL. The energy management, the activation and the selection of FXOSC as system clock are controlled by the mode entry MC_ME module.
The only register which controls the FXOSC is FXOSC_CTL (p 73). OSCBYP controls the bypass of the oscillator, EOCV counter specifies the duration for oscillator stabilization checking. The interrupt linked to FXOSC clock failure is enabled by the bit M_OSC. The related interrupt request (IRQ) vector is the vector number 57. The flag bit I_OSC indicates if an oscillator clock interrupt is pending. It must be cleared by writing a ‘1’. The output division factor applied on the oscillator clock is defined by the field OSCDIV[4:0]. The division factor is equal to OSCDIV+1.


Address offset: 0x0000
Base Address: 0xC3FE0000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
OSCBYP
Reserved
EOCV[7:0]
Access rs — rw
Reset 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
M_OSC
Reserved
OSCDIV[4:0]
I_OSC
Reserved
Access rw — rw rc —
Reset 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

After reset, FXOSC is placed in powerdown mode. Its switch on is controlled by software through the MC_ME module (ME_<mode>_MC register, FXOSCON bit). The availability of a stable oscillator clock is indicated by the status bit S_FXOSC in the register ME_GS of the MC_ME module.

3. FM PLL

Refer to chapter 3.7 for more information about FMPLL. The FMPLL enables the generation of high speed clock (from 16 MHz to 64 MHz) from 4-16 MHz clock source, which can be configured by software. FMPLL supports frequency modulation of the system clock in order to reduce electromagnetic interference emission. The modulant signal is a triangular waveform, with frequency up to 100 KHz and modulation depth comprised between 0 and 2 %. The energy management, the activation and the selection of FMPLL as system clock are controlled by the mode entry MC_ME module.

Fig. 3 presents the block diagram of the FMPLL. The frequency of the PLL output (PHI) depends on register IDF, ODF and NDIV, according to the following formula: $phi = \frac{clkin \times NDIV}{IDF \times ODF}$. The selection of NDIV, IDF and ODF register content must be done with the following constraints:

- The VCO frequency range is between 256 and 512 MHz. If you try to make it operate at lower or larger frequency, the PLL operation could be degraded.
- NDIV values must be ranged between 32 and 96
- IDF can accept any number between 1 and 15
- ODF is coded on 2 bits in order to represent only 4 values: 2, 4, 8 or 16

For example, let's suppose that the FXOSC is the source generator for the PLL and delivers a 8 MHz clock: clkin = 8 MHz. Let's suppose that we want to generate a PLL output frequency equal to 45 MHz: phi = 45 MHz. A possible configuration is: NDIV = 90, IDF = 2, ODF = 8. With this configuration, the VCO operates at 360 MHz.

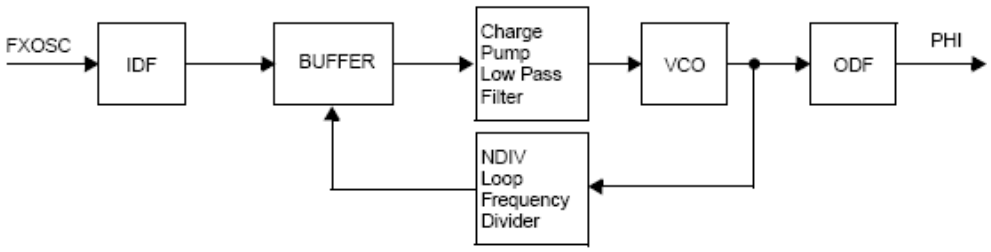


Figure 3 – FMPLL block diagram (Bolero512K_RM_Rev7_07_2010.pdf - p. 80 – Fig. 3-6)

The configuration of the PLL operation is controlled by the register FMPLL_CR. The register fields IDF, ODF and NDIV sets the PLL output frequency. These values must be changed only when the PLL is not selected as clock source. Setting the bit EN_PLL_SW enables the progressive clock switching which improves the transition to FMPLL as system clock. Loss of lock and PLL failure are indicated by the bits UNLOK_ONCE, S_LOCK and PLL_FAIL_FLAG.

Offset 0x0000 Access: Supervisor read/write

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	IDF[3:0]				ODF[1:0]		0	NDIV[6:0]						
W																
Reset	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	0	0	0	0	0	EN_PLL_SW	0	UNLOCK_ONCE	0	I_LOCK	S_LOCK	PLL_FAIL_MASK	PLL_FAIL_FLAG	0
W												w1c			w1c	
Reset[1]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The configuration of the frequency modulation is set by the register FMPLL_MR. Three parameters need to be defined as shown in Fig. 4: the period of the modulant signal (Tmod), the modulation depth (Mod_depth (%) = 100×md/Fmod) and the type of spreading (center spread or down spread), where Fmod is modulation frequency and md the amplitude of frequency excursion. The modulation depth or index is limited to +/-2 % (center spread) ou -4 % (down spread), the maximum modulation frequency is 100 KHz.

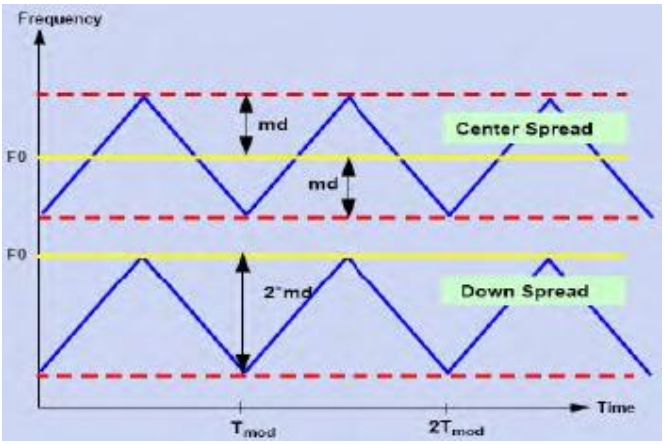
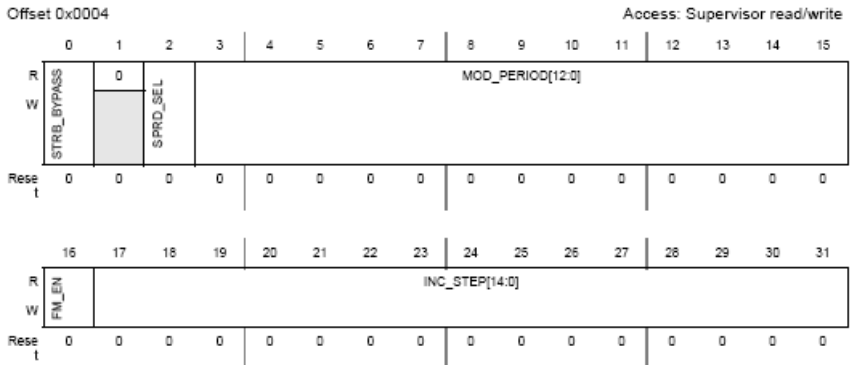


Figure 4 – Frequency modulation principle in FMPLL block (Bolero512K_RM_Rev7_07_2010.pdf - p. 87 – Fig. 3-10)

The field MOD_PERIOD sets the modulant period. Its equivalent binary value is equal to: $MOD\_PERIOD = \frac{F_{ref}}{4 \times F_{\mathrm{mod}}}$, where Fref is the frequency at the output of the feedback divider (NDIV). The field INC_STEP sets the modulation index. Its equivalent binary value is equal to: $INC\_STEP = round\left(\frac{\left(2^{15} - 1\right) \times NDIV \times Mod\_depth\,\%}{100 \times 5 \times MODPERIOD} \right)$. The type of spread is defined by the bit SPRD_SEL. If STRB_BYPASS bit is set, the field INC_STEP, MOD_PERIOD and the bit SPRD_SEL must be changed only when the PLL is in powerdown mode. The frequency modulation is enabled by setting the bit FM_EN. The FM must be enabled only when the PLL is active.



After reset, FMPLL is placed in powerdown mode. Its switch on is controlled by software through the MC_ME module. Its switch on is controlled by software through the MC_ME module (ME_<mode>_MC register, FMPLLON bit).
The availability of a stable FMPLL clock is indicated by the status bit S_FMPLL in the register ME_GS of the MC_ME module.

IV - Mode entry module (MC_ME)

This block controls the different modes of the MCU and the transition sequences between the different modes. The notions of modes and transitions between modes are essential to configure the MCU correctly and initiate the user mode, which the normal operation mode.

Refer to chapter 5 – Mode entry module for more details about the MPC5604's modes.

1. Presentation of the different modes

The MCU proposes different modes corresponding to different usages (system configuration and monitoring, user mode, low power modes…) (refer to table 5-1 p 113/956). The embedded software executes only in DRUN, SAFE, TEST and RUN0..RUN3 modes. RESET, DRUN, SAFE and TEST modes are system modes. They are dedicated to the configuration and the monitoring of the system. RUN0..RUN3, HALT0, STOP0 and STANDBY0 are user modes. HALT0, STOP0 and STANDBY0 are low power modes. In the next chapter (Wakeup Unit), the procedure to exit these low power modes will be detailed. The configuration of the MCU mode depends on the requirements in term of energy management and processing power.

- RESET: the application is not active, the chip configuration is initialized. The system enters in this mode after a reset.

- DRUN: entry mode for the embedded software. It enables the configuration of the system at the start-up. This is the only mode entry to a user mode. If the embedded software does not enable a transition between DRUN mode and a user mode, the main program defined by the user cannot execute. The system enters in this mode after the end of Reset mode, and after software request from RUN0..RUN3, SAFE, TEST modes, and a wake up request from STANDBY mode.

- SAFE: the system enters in this mode after the detection of a recoverable error. The system exits this mode after a reset or DRUN from software.

- TEST: for device self-test. The system enters in this mode from DRUN mode by software request. The system exits this mode after a reset or by software request to come back in DRUN mode.

- RUN0 .. RUN3: these are the embedded software modes where most processing activity is done. 4 RUN modes are provided to enable different power and clock configuration. The system enters in one of these modes after DRUN by software request, interrupt event from HALT0, interrupt or wake up event from STOP0. The system exists one of these modes after reset, entry in SAFE mode after an hardware or software error, HALT0, STANDBY0 or STOP0 by request.

- STOP0: Reduced activity low power mode. The wakeup signals are processed rapidly, contrary to HALT mode. By default system clock is FIRC, but it can be switched off. The data and flash memories are powered down but can be activated; the main regulator is switched on. See chapter Wakeup Unit for more details about the exit of STOP0 mode.

- HALT0: Reduced activity low power mode. The clock core is disabled. The analog peripherals can be switched off. The system enters in this mode by software request from RUN0..RUN3 modes. The systems leaves this mode after a reset, after a hardware or software failure to go in SAFE mode, or interrupt event to come back in

previous RUN0..RUN3 modes. Contrary to STOP0 and STANDBY0 modes, wakeup signals cannot be used to exit from HALT0 mode.

- STANDBY0: This is the most low power mode which ensures a reduced leakage current. Most of the blocks of the MCU are switched off from the power supply to reduce leakage current. Wake up from this mode is quite long. The system enters in this mode by software request from DRUN, RUN0..RUN3 modes. The system leaves this mode after reset, of after wake up event to enter in DRUN mode (see chapter Wakeup Unit). The wakeup from STANDBY0 mode is longer than from STOP0 mode. All the pins are in high impedance mode. Only the reset generation mode, power control unit, wake up unit, 8K RAM, RTC/API, CAN sampler, SIRC, FIRC, FXOSC are powered.

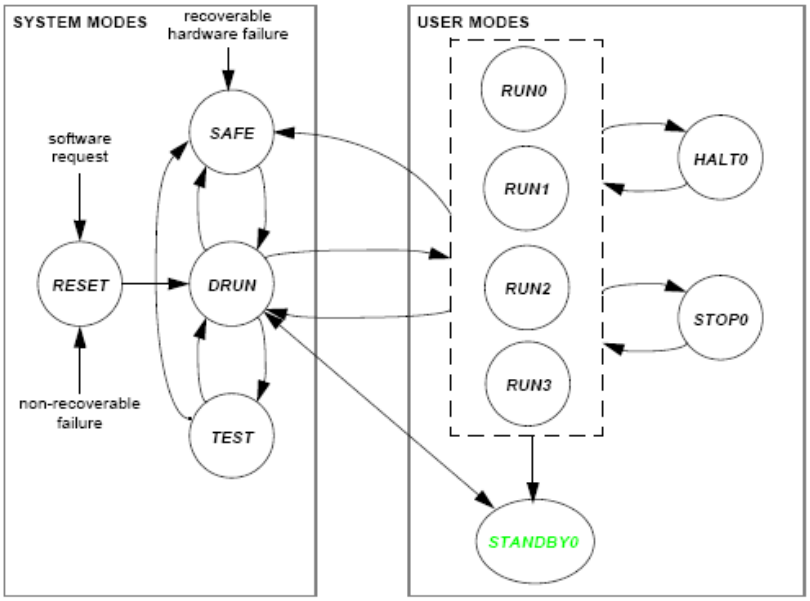


Figure 5 – Mode entry diagram and possible mode transitions (Bolero512K_RM_Rev7_07_2010.pdf - p. 144 – Fig. 5-24)

2. Mode entry module registers

a. Enabling modes

The Mode Enable Register MER allows enabling or disabling some MCU modes (except RESET, DRUM, SAFE and RUN0).

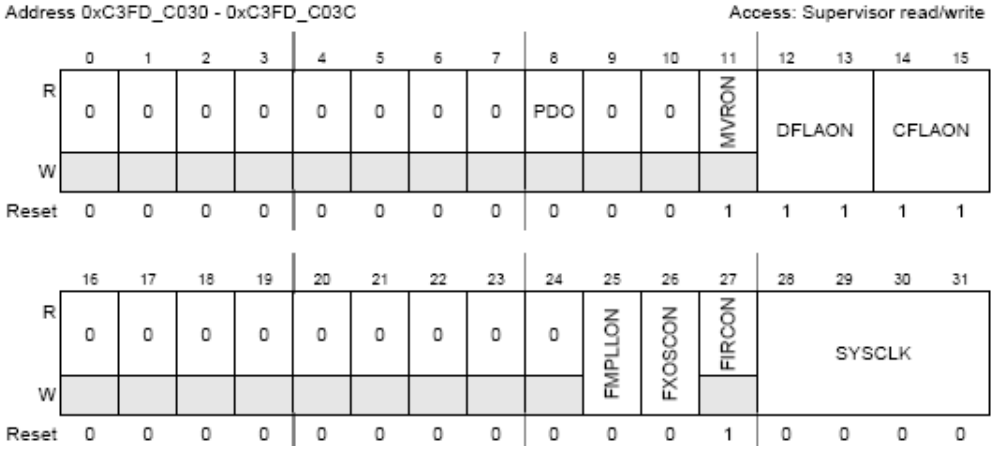
Address 0xC3FD_C008 Access: Supervisor read/write

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	STANDBY0	0	0	STOP0	0	HALT0	RUN3	RUN2	RUN1	RUN0	DRUN	SAFE	TEST	RESET
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1

b. Mode configuration

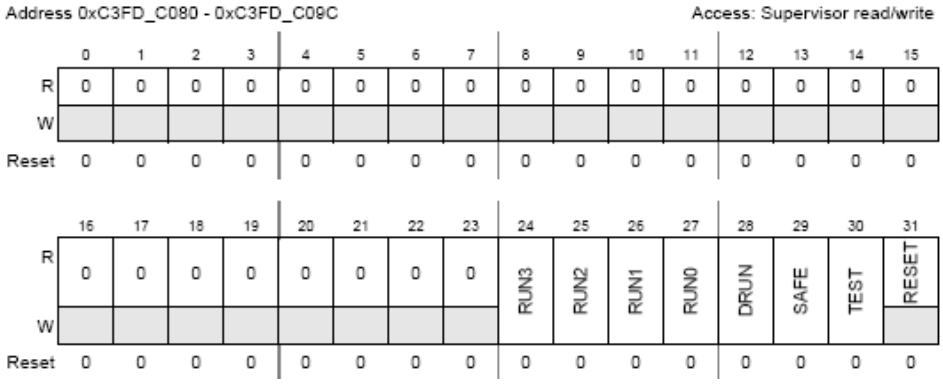
A mode configuration register is associated to each mode to control the connection or disconnection of some peripherals in the mode, such as the I/O output buffers, internal voltage regulator, data and code flash memory, PLL, fast external crystal and RC oscillators. It specifies also the system clock used by the system (PLL, crystal oscillator, fast RC oscillator…). All these registers have the same structure. The following figure shows the register structure for RUN0 .. RUN3 mode configuration registers, called ME.RUN[0] to ME.RUN[3].



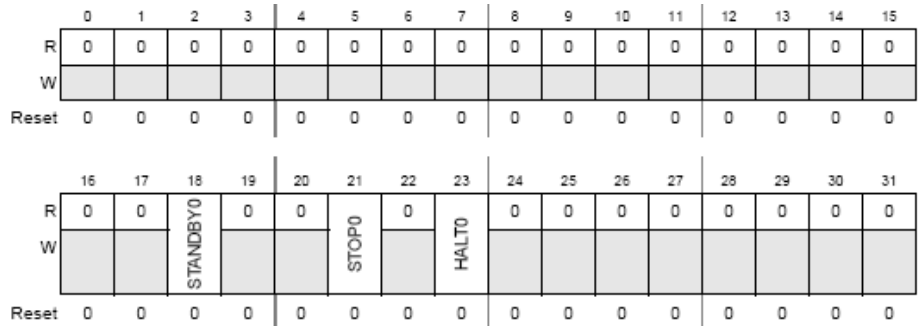
c. Peripheral configuration

Up to eight different behaviors can be configured for the peripherals of the MCU in the different run modes. These 8 behaviors are defined by the Run Peripheral Configuration Registers 0 to 7 (RUNPC[0] to RUNPC[7]).

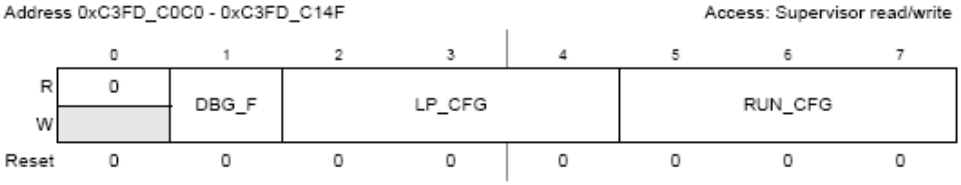
Setting a bit associated to a mode to ‘0’ means that, if this configuration is given to a peripheral, this peripheral will be frozen in with clock gated during this mode. If this bit is set to ‘1’, the peripheral will be active. For example, let’s suppose that we define one behavior in RUNPC[0] and we write 0x00000030. If this configuration is associated to one peripheral, this peripheral will be active only in RUN0 and RUN1 mode. In all other modes, it will be frozen.



For the 3 non run modes (STANDBY0, HALT0 and STOP0), 8 behaviors can also be configures through the registers Low Power Peripheral Configuration LPPC[0]to LPPC[7].



Once the different possible behaviors have been configured with registers RUNPC[0]to RUNPC[7], these behaviors can be associated to the 144 peripherals of the MCU. 144 registers called Peripheral Control Registers PCTL[0]to PCTL[143] are associated to each peripheral. These registers contains 3 fields: the field RUN_CFG defines which one of the 8 behaviors defined in RUNPC[0] to RUNPC[7] will be associated to the peripheral during the run modes. The field LP_PC defines which one of the 8 behaviors defined in LPPC[0] to LPPC[7] will be associated to the peripheral during the non run modes. The bit DBG_F sets the behavior of the peripheral in Debug mode.



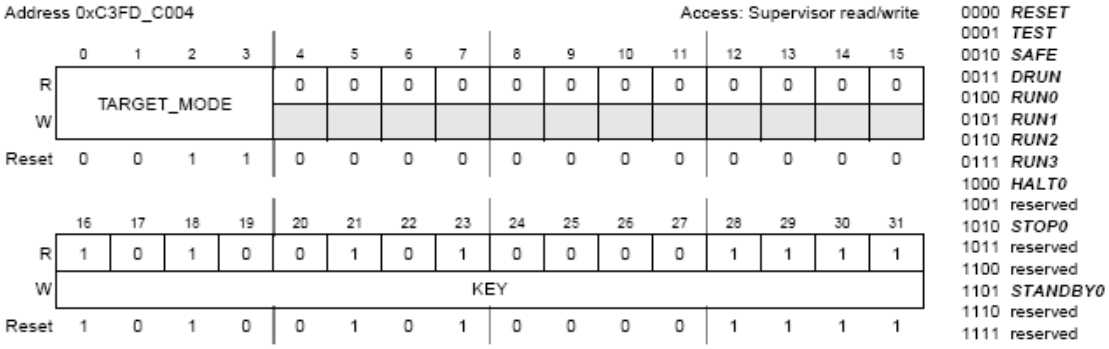
The status of the peripherals is given by the registers PS0, PS1, PS2 and PS3.

Remark: one number from 0 to 143 is associated to each peripheral. The following table (Table 3-1 p 71/956) gives the number associated to each peripheral. For example, the number 32 is associated to the ADC block, the number 68 to the SIUL module (GPIO). The configuration of the ADC behavior according to the mode will be defined by register PCTL[32] and the configuration of the SIUL behavior by PCTL[68].

Peripheral	Register gating address offset (base = 0xC3FDC0C0)[1]	Peripheral set[2]
RPP_Z0H Platform	none (managed through ME mode)	—
DSPI_n	4+n (n = 0..2)	2
FlexCAN_n	16+n (n = 0..5)	2
ADC	32	3
I^2C	44	1
LINFLEX_n	48+n(n = 0..3)	1
CTU	57	3
CANS	60	—
SIUL	68	—
WKUP	69	—
eMIOS_n	72+n (n = 0..1)	3
RTC/API	91	—
PIT	92	—
CMU	104	—

d. System mode selection and transition

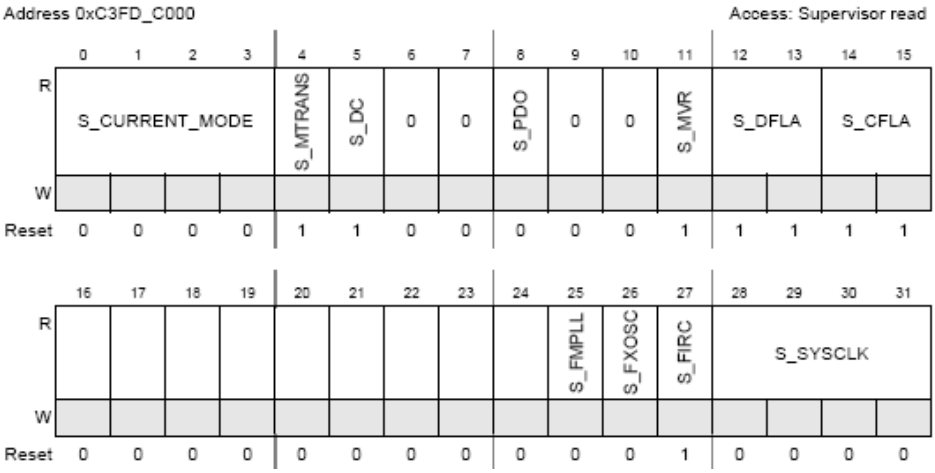
The Mode Control Register MCTL is used to trigger mode change by software. The TARGET_MODE field defines the target mode to be entered by software request.



The KEY field is a control key to enable the writing in this register. The KEY is 0x5AF0. A different value is invalid and any writing in the register will be ignored. Actually, two writing of the register have to be done to force the device to enter in the mode defined by TARGET_MODE: first time with the good value of the key, a second time with the inverted value of the key. For example, suppose that we want the system to exit DRUN mode to enter RUN0 mode. The TARGET_MODE field must be equal to '0100'. Therefore, the two following lines have to be written in the software:

```
ME.MCTL.R = 0x40005AF0;        /* Enter the target mode and the Key */
ME.MCTL.R = 0x4000A50F;        /* Enter the target mode and the inverted Key */
```

The global mode status of the system is given by the register Glogal Status Register GS. The field S_CURRENTMODE notifies the current device mode. The bit S_MTRANS notifies if a mode transition is on-going. It gives also the status of several MCU peripherals.



3. Summary – MCU initialization procedure

The procedure to initialize the MCU is always the same and describes below. This procedure must be done in DRUN mode.

1. Enables the modes to be used
2. Configure the clock sources
3. Configure the modes to be used
4. Configure the peripherals

5. Switch from DRUN mode to a user mode (RUN0,1,2,3)

Remark:
When the MCU is in debug mode, the Software Watchdog (SWT) is disabled (See chapter Software Watchdog). In nominal operation, the SWT is activated. The SWT must be stopped or checked regularly to avoid unwanted MCU reset. Refer to chapter Software Watchdog of this document or chapter 28.2 of the MCU datasheet from more information about the configuration of the SWT.

V - Wake up Unit (WKPU)

This block manages the events which trigger a transition from low power modes (HALT0, STOP0 and STANDBY0) to RUN0..3 or DRUN modes. Refer to chapter 30 – Wakeup Unit for more details.
The microcontroller exits a low power mode either after a reset assertion, a interrupt request or a wakeup event (except for Halt0 mode). The wakeup signal can originate from 20 sources, either internal (API and RTC) or external (specific pads such as CAN or LIN), as shown in the following table. Three interrupts are associated to these events.

The following table shows different wakeup sources, their id numbers, modules associations and flags.

Wakeup number	Port	SIU PCR#	Port input function[1] (can be used in conjunction with WKPU function)	WKPU IRQ to INTC	IRQ#	WISR	Register[2] bit position
WKPU0	API	n/a[3]	—	WakeUp_IRQ_0	46	EIF0	31
WKPU1	RTC	n/a[3]	—			EIF1	30
WKPU2	PA1	PCR1	NMI			EIF2	29
WKPU3	PA2	PCR2	—			EIF3	28
WKPU4	PB1	PCR17	CAN0-RX			EIF4	27
WKPU5	PC11	PCR43	CAN1-RX, CAN4-RX			EIF5	26
WKPU6	PE0	PCR64	CAN5-RX			EIF6	25
WKPU7	PE9	PCR73	CAN2-RX, CAN3-RX			EIF7	24
WKPU8	PB10	PCR26	—	WakeUp_IRQ_1	47	EIF8	23
WKPU9	PA4	PCR4	—			EIF9	22
WKPU10	PA15	PCR15	—			EIF10	21
WKPU11	PB3	PCR19	LIN0-RX			EIF11	20
WKPU12	PC7	PCR39	LIN1-RX			EIF12	19
WKPU13	PC9	PCR41	LIN2-RX			EIF13	18
WKPU14	PE11	PCR75	LIN3-RX			EIF14	17
WKPU15	PF11	PCR91	—			EIF15	16
WKPU16	PF13	PCR93	—	WakeUp_IRQ_2	48	EIF16	15
WKPU17	PG3	PCR99	—			EIF17	14
WKPU18	PG5	PCR101	—			EIF18	13
WKPU19	PA0	PCR0	—			EIF19	12

[1] This column does not contain an exhaustive list of functions on that pin. Rather, it includes peripheral communication functions (such as CAN and LINFlex Rx) that could be used to wake up the microcontroller. DSPI pins are not included because DSPI would typically be used in master mode.
[2] WISR, IRER, WRER, WIFEER, WIFEEF, WIFER, WIPUER
[3] Port not required to use timer functions.
[4] Unavailable WKPU pins must use internal pullup enabled using WIPUER.

Several registers are dedicated to the configuration and the management of wakeup events. The register WIFER enabled the different wakeup sources. Writing a '1' in one of the 20 positions of the field IFE[19:0] enables one the wakeup event (see previous table to find the number associated to a wakeup source).

Address: 0x0030 Access: User read/write

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	0	0	0	0	0	0	0	0	0	0	IFE[19:0][1]																			
W																																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The register IRER enables interrupts generation when wakeup events are detected. The register WISR contains the interrupt flags. The wakeup event is activated either on rising or falling edge, depending on the configuration of register WIREER and WIFEER.

VI - GPIO pad configuration (System Integration Unit Lite)

Refer to Chapter 8 – System Integration Unit Lite for the configuration of General Purpose I/O (GPIO) pads and the multiplexing of alternate functions associated to GPIO.

1. Presentation

MPC5604B proposes 123 GPIO in its LQFP144 package version, organized in 8 ports (from Port A to H). Except port H, each port contains 16 I/O pads. All the pad can be configured independently through the PCR[0] to PCR[122] registers. The number of the PCR register related to a given pad can be found in Table 2-3 p. 45. For example, the pad PA[0] is associated to the register PCR[0], pad PA[1] to PCR[1] and pad PH[10] to PCR[122].
One input register GPDI and one output register GPDO are associated to each pad. 15 GPIO are associated to External Interrupt Request (EIRQ) pins (EIRQ[0:15]). They can trigger interrupt on rising edge or falling edge events, depending on the configuration of registers SIUL_IREER and SIUL_IFEER. Some glitch filter can be configured at the input of these pins.

2. Pad configuration

The 123 pads of SIUL can be individually configured by the registers PCR[0] to PCR[122].

Address: Base + 0x0040 (PCR0)(123 registers) Access: User read/write
Base + 0x0042 (PCR1)
...
Base + 0x0130 (PCR122)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R		SMC	APC		PA[1:0]		OBE	IBE			ODE			SRC	WPE	WPS
W																
Reset	0	0^1	0	0	0^1	0	0^2	0^3	0	0	0	0	0	0	0^3	1^4

Four output buffer, the alternate function is selected by the field PA[1:0]. Up to 4 alternate functions are associated to a pad. By default, the field is equal to '00' and the pad operates as a GPIO. In case of GPIO mode, the output buffer is enabled if OBE bit is set. The output driver can be configured as open drain output through the bit ODE. The SRC bit controls the

slew rate of the output pad. By default, the pad is slow. By setting SRC to '1', the pad is configured as medium or fast.
For input pad, the input buffer is enabled by the bit IBE. If the pad is used as analog input, the bit APC must be set. WPE and WPS bits enable weak pull-up and pull-down device on a pad.
In some cases, the input signal of a peripheral (such as CAN, LIN, SPI buses) can be provided by several pins. For example, the reception input of CAN1 module CAN1_RXD can be provided by three pads: PC[3], PC[11] or PF[15]. It is therefore necessary to specify the associated pad. First, the correct alternate function has to be selected on the PCR register of the pad. Then, the pad used for the peripheral is specified in the register PSMI. See Table 8-13 p. 218 for the configuration of PSMI registers.

3. GPIO Data registers

Data can be read or write pad by pad or port by port. The data are written on individual output pads by the bit PDO of the registers GPDO[n], n = 0 to 123. The data are read from individual input pads by the bit PDI of the registers GPI[n], n = 0 to 123.
A port can be completely written or read in one operation by the registers PGPDO0 – PGPDO3 (output data) and PGPDI0 – PGPDI3 (input data). The most significant bit of the parallel port register corresponds to the least significant pin in the port. For example, bit PA[0] is mapped to the most significant bit of PGPDO0 and bit PB[15] is mapped to the least significant bit of PGPDO0.

Offset[1]	Register	Field	
		0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
0x0C40	PGPDI0	Port A	Port B
0x0C44	PGPDI1	Port C	Port D
0x0C48	PGPDI2	Port E	Port F
0x0C4C	PGPDI3	Port G	Port H

It is also possible to write on output ports through a mask, defined by the registers MPGPDO0 to MPGPDO7. Each 32 bit register is associated to one port. The 16 most significant bits of the register define the mask (field MASK). The 16 least significant bits define the data to be written on the output buffer (field MPPDO).

Offset[1]	Register	Field	
		0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
0x0C80	MPGPDO0	MASK0 (Port A)	MPPDO0 (Port A)
0x0C84	MPGPDO1	MASK1 (Port B)	MPPDO1 (Port B)
0x0C88	MPGPDO2	MASK2 (Port C)	MPPDO2 (Port C)
0x0C8C	MPGPDO3	MASK3 (Port D)	MPPDO3 (Port D)
0x0C90	MPGPDO4	MASK4 (Port E)	MPPDO4 (Port E)
0x0C94	MPGPDO5	MASK5 (Port F)	MPPDO5 (Port F)
0x0C98	MPGPDO6	MASK6 (Port G)	MPPDO6 (Port G)
0x0C9C	MPGPDO7	MASK7 (Port H)	MPPDO7 (Port H)

4. EIRQ pins

16 GPIO are also defined as external IRQ input pins. Any rising or falling edge events can trigger maskable interrupts. Two interrupts are associated to EIRQ. The 8 first EIRQ are associated to interrupt request IRQ0 (interrupt vector number 41), the 8 last EIRQ are associated to interrupt request IRQ1 (interrupt vector number 42).
The interrupt request associated to each EIRQ input can be individually enabled by the register IRER. Each time an interrupt is pending, the flag bit EIF of the register ISR is set to

'1'. Writing a '1' clears the flag. Interrupt can arise on rising and/or falling edge events on EIRQ input pins. It can be configured by the registers IREER and IFEER.
Noise coupled on input pins can induce glitches that may be misread as a rising or falling edge. Therefore, digital glitch filter can be enabled on each EIRQ inputs, by setting bits IFE in IFER register. The digital glitch filters are configured by the registers IFMC0-IFMC15 and IFCPR0-IFCPR15.

VII - Interrupt configuration

Refer to Chapter 10 – Interrupt Controller (INTC) for the configuration of priority of the different interrupt source.

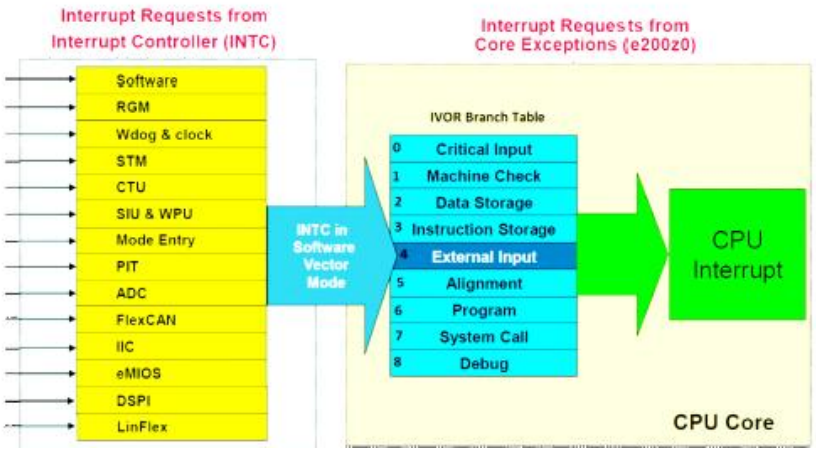
1. Interrupt service request (ISR) in MCU

All the real-time controllers in interaction with their environment operate by interruption of their on-going program. The execution of functions depends on external events (e.g. pushed button, detection of a voltage above a given threshold, reception of a signal…). The interrupt service requests (ISR) are predefined and associated either to hardware peripherals, resets or software requests. When the conditions for the triggering of an interrupt are detected by the CPU, the execution of a function dedicated to the ISR processing can launched, depending on the interrupt configuration (interrupt enabled or not if the interrupt is maskable), the content of interrupt vector table and the level of priority of the ISR.
The interrupt vector table is an area of the memory divided in interrupt vectors. Each interrupt vector has a fixed memory address and is associated to a given ISR (e.g. edge detection on an input digital buffer or time-out of a timer). At the address of the interrupt vector, the memory contains the address of the function dedicated to the processing of the ISR (for example, when an edge is detected on an input digital buffer, the programmer wants to launch a program that switch on an external LED). The programmer must know exactly the address of interrupt vector in order to associate an ISR to the execution of a processing function.
When an ISR is triggered during the execution of the main program, the address of the next instruction of the main program must be saved, in order to come back to the main program after the processing of the interrupt. In practice, before stopping the execution of the main program and launch the interrupt program, the content of the program counter is saved and will be updated at the end of the interrupt program.
The interrupt management is complex and is done by an interrupt controller (INTC) which aims at scheduling the ISR, i.e:

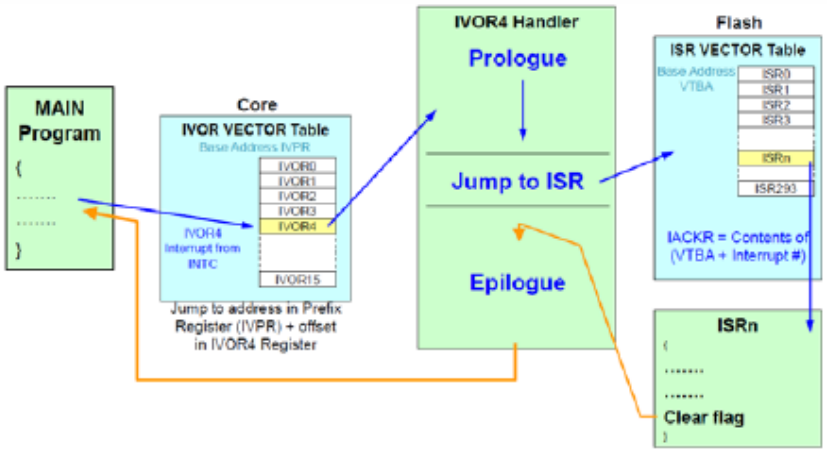
- Notifying the CPU that an ISR is transmitted by a peripheral or the software
- Managing the priorities between the different incoming ISR
- Transmitting to the CPU the address of the program to process the interrupt

2. Presentation of INTC and interrupt vector

The following figure describes how interrupt requests are handling and the position of the INTC block. In the MCU core (e200z0h), registers called Interrupt Vector Offset Register (IVOR) forms a branching table which handles the different exceptions which occur during the MCU operation. IVOR4 is the register used for interrupt handling.



The INTC module of the MPC5604B manages the ISR based on their programmable priorities and triggers IVOR4 exceptions. The following figure details how an ISR is handled in a mode called software mode (two ISR handling modes are proposed: hardware and software. Only software mode is considered in this document).



The MCU has 142 ISR (see Table 10-1 p 242 for the detail about the source of available ISR):

- 134 ISR are associated to peripherals (hardware (HW) triggered ISR)
- 8 ISR which can be configured by software (software (SW) triggered ISR)

Remark: SW triggered ISR are dedicated to:

- In a multiprocessor context, interruption of a processor activity by another processor
- In a program launched by a high level ISR, if a part of the program has a low level priority, it is possible to suspend the execution of this part by a software ISR. It improves the management of dead-lines of operation.

The priority of each ISR can be configured, with a level from 0 (lowest priority) to 15 (highest priority). Most of the HW triggered interrupts are maskable, i.e. it is possible to inhibit the ISR transmission to the INTS by the peripheral, by setting an interrupt enable bit (see configuration registers of each peripheral to know how to mask interrupt). Each time an ISR is launched, a flag bit is set. One flag bit is associated to one ISR source. The flag bits are in interrupt flag registers associated to the peripherals.

Important: don't forget to reset flag bit after ISR triggering. The flag indicates to the INTC that the peripheral sent an ISR. If the flag remains set, no more ISR can be generated. Most of the time, it is necessary to write a '1' in the flag bit to reset it. This is a particularity of Freescale MCU.

Table 10-10 p. 253 gives the interrupt vector table of the MPC 5604B. The address of an interrupt vector is given in the following format:

Base address + Vector number

The vector number starts at 0 (for the software ISR number 0) up to 210 (for ISR launched by buffers 32 to 63 of FlexCAN5).
In order to associate an ISR coming from a peripheral or the software and a program to process the ISR, an interrupt handler has to be defined. This interrupt handler writes the address of the interrupt processing program at the interrupt vector address, and manages the ISR priority. We will see how to deal with interrupt handler with hardware or software ISR in the MPC5604B.

3. Enabling maskable interrupt

Maskable interrupt must be enabled at two levels: at local level (i.e. at peripheral level) by a interrupt enable bit associated to ISR source, and at global level. In order to enable ISR in the MCU, you must execute this routine in your program:

```
void enableIrq(void) {
  INTC.CPR.B.PRI = 0;          /* Single Core: Lower INTC's current priority */
  asm(" wrteei 1");             /* Enable external interrupts */
}
```

4. Configuring hardware triggered interrupt

HW triggered interrupt are most of the time maskable interrupt, so the peripheral configuration must enable ISR and the maskable interrupt must enabled at global level. INTC is implemented in several files: INTCInterrupt.h, INTCInterrupt.c, Eceptions.h, Exceptions.c. They contain the routines used to execute the ISR handling procedure. The following function configure the interrupt handler and the interrupt priority:

INTC_InstallINTCInterruptHandler(My_ISR_program,vector_number,priority_level);

My_ISR_program is the name of the program that the programmer wants to launch when the ISR is triggered by the peripheral. Vector_number is the number of the interrupt vector associated to the ISR (see Table 10-10 p. 253). Priority_level is the level of priority associated to the ISR and ranges from 0 to 15.
For example, let's suppose that you design a program that launches the periodic interrupt timer Timer PIT1. At each time-out of PIT1, you want to trigger an interrupt that launches a function called My_PIT_ISR_function. The vector number of the ISR associated to PIT1 is 60 (according to Table 10-10 p. 253). You want to give a priority level equal to 2 to the PIT1 ISR. In order to enable the PIT interrupt, you have to proceed as following:

1. Initialize PIT1 and enable interrupt
2. Interrupt handler for the PIT1 ISR: INTC_InstallINTCInterruptHandler (My_PIT_ISR_function,60,2);
3. Enable maskable interrupt in the MCU: enableIrq();

4. In the function My_PIT_ISR_function, you have to clear the flag associated to PIT1 ISR.

5. Configuring software triggered interrupt

Use the same procedure as HW triggered interrupt to configure SW triggered interrupt.
The only difference relies in the triggering of software interrupt. Hardware interrupt is triggered by a hardware event (external event, time-out of a timer…). A software interrupt is triggered by a program request.
The registers SSCIR[i], i = 0..7, of the INTC modules support the setting or the clearing of software configurable ISR. A couple of 2 bits : SETi/CLRi sets or clear each software ISR. Writing a '1' to SET set the flag bit CLR to '1'.Writing a '0' has no effect. If the CLR bit is set to '1' it indicates that an ISR is pending, like any other flag bit. The flag CLR is cleared by writing a '1'.

Offset: 0x0024 Access: User read/write

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0	0	0	0	0	CLR4	0	0	0	0	0	0	0	CLR5
W							SET4								SET5	
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	0	0	0	0	0	CLR6	0	0	0	0	0	0	0	CLR7
W							SET6								SET7	
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VIII - Analog-to-digital converter (ADC)

Refer to Chapter 26 – Analog-to-Digital Converter (ADC) for the principles and the configuration of ADC.

1. Presentation

The ADC block contains 36 analog channels internally multiplexed to the 10 bit resolution ADC machine. These 36 analog channels are divided between:

- 16 precision channels called ANP[0]to ANP[15]
- 20 standard channels called ANS[0] to ANS[15] and ANX[0] to ANX[3] which are externally multiplexed.

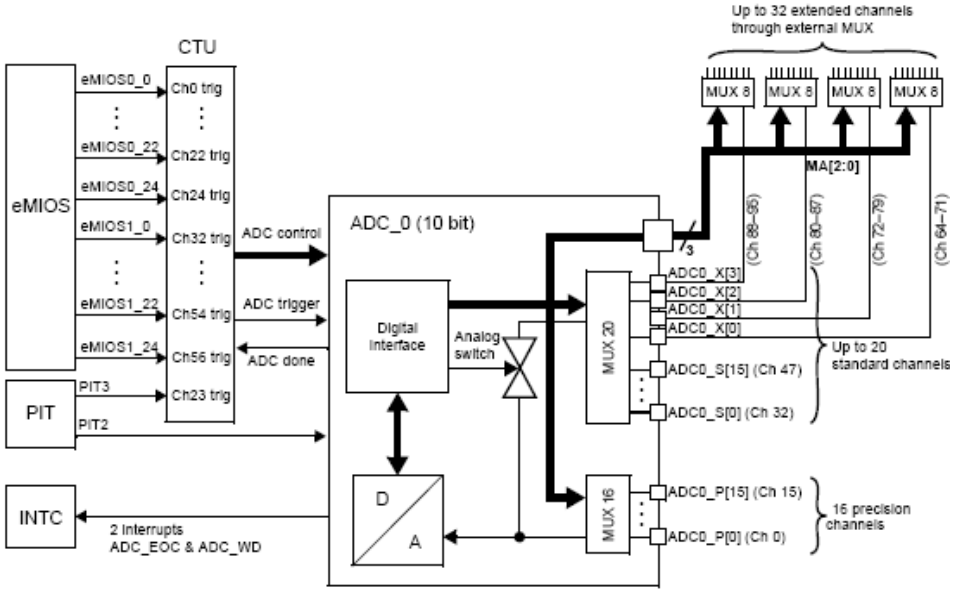
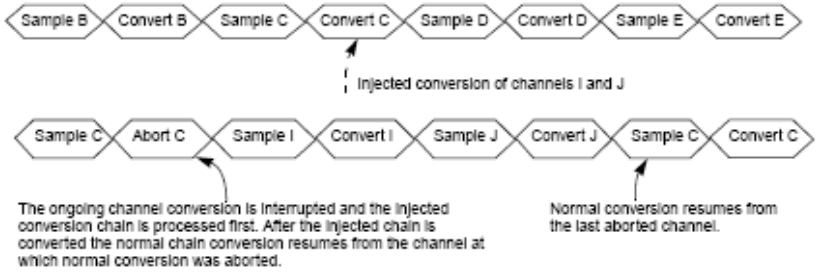


Figure 6 – Block diagram of ADC (Bolero512K_RM_Rev7_07_2010.pdf - p. 726 – Fig. 26-1)

The conversion can be triggered by software or hardware (CTU block (see chapter IX of this document) or timer PIT2, not described in this document). Three types of conversion are proposed:

- Normal conversion mode: in this mode, the conversion process consists in two phases: a sampling of an analog channel, and then the conversion of the sampled channel. In normal mode, two sub-modes are proposed: in one shot mode, only one sequential conversion is launched for all the activated analog channels. In scan mode, the sequential conversions are done on each activated analog channels continuously. In normal mode, the change of the configuration must be done before the launching of the conversion.

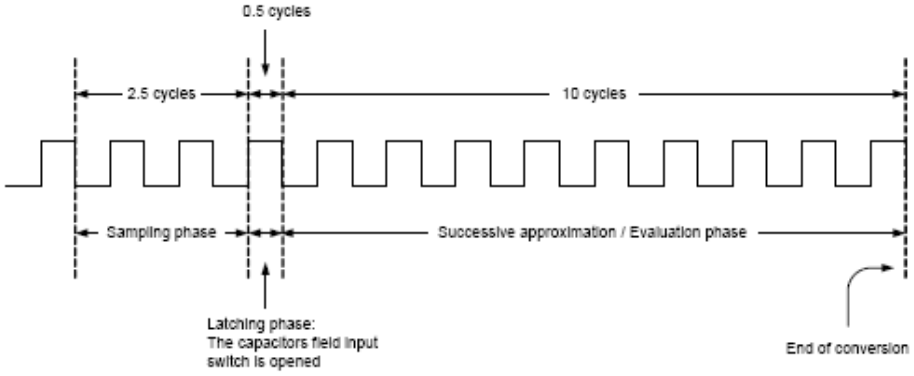
- Injected channel conversion mode: the normal conversion process can be interrupted to inject the conversion of another channel.


Sample B
Convert B
Sample C
Convert C
Sample D
Convert D
Sample E
Convert E
Injected conversion of channels I and J
Sample C
Abort C
Sample I
Convert I
Sample J
Convert J
Sample C
Convert C
The ongoing channel conversion is interrupted and the injected conversion chain is processed first. After the injected chain is converted the normal chain conversion resumes from the channel at which normal conversion was aborted.
Normal conversion resumes from the last aborted channel.

- CTU triggered conversion mode: improvement of the injection mode, where the synchronization is provided by an external event (PIT3 or eMIOS block). Normal and injected conversions triggered by the CPU are still enabled. Refer to chapter IX of this document for the configuration of CTU module.

The ADC block proposes several features for the conversion. It proposes a pre-sampling. It consists in precharging or discharging the ADC sampling capacitor just before the sampling step, in order to improve the conversion quality. Two fixed voltages can be sampled during

this operation: Vdd_HV_ADC or Vss_HV_ADC, which are two external voltage references for the ADC.
The conversion timing can be configured accurately, with the register CTR. The ADC is clocked by the peripheral clock, or by the peripheral clock with a frequency divided by 2. The CTR register defines for each type of channel the three step of a conversion: the sampling phase (the ADC sampling capacitor is connected to the selected analog channel), the latching phase (the sampling capacitor is disconnected of the analog channel, this sequence lasts one half a ADC clock period), and the evaluation phase (this is the analog-to-digital conversion, based on a successive approximation, which can last 10 clock period for a 10 bit conversion).



Note: Operating conditions – INPLATCH = 0, INPSAMP = 3, INPCMP = 1and Fadc clk = 20 MHz

Figure 7 – Sampling and conversion timings (Bolero512K_RM_Rev7_07_2010.pdf - p. 731 – Fig. 26-4)

The CTR register is composed of three fields to configure the conversion time: INPLATCH, INPCMP and INPSAMP. The conversion time can be computed according to the following formula:

$$T_{Sample} = (INDSAMP - N_{delay}).T_{Clk} \ , \ INDSAMP \geq 3 \ , \ N_{delay} = 0.5 \ si \ INDSAMP \leq 0x06 \ , \sin on 1$$

$$T_{Eval} = 10.T_{Eval} = 10.INPCMP.T_{Clk} \ , \ INPCMP \geq 1, \ INPLATCH \ \leq INPCMP$$

$$T_{Conv} = T_{Samp} + T_{Eval} + N_{Delay}.T_{clk}$$

The INPCMP and INPSAMP configurations are limited if the clock frequency is greater than 20 MHz. The selection of correct values for these fields can be delicate. The following table gives nominal values depending on ADC clock frequency.

Clock (MHz)	T_{ck} (µs)	INPSAMPLE[1]	Ndelay[2]	T_{sample}[3]	T_{sample}/T_{ck}	INPCMP	T_{eval} (µs)	INPLATCH	T_{conv} (µs)	T_{conv}/T_{ck}
6	0.167	4	0.5	0.583	3.500	1	1.667	0	2.333	14.000
7	0.143	4	0.5	0.500	3.500	1	1.429	0	2.000	14.000
8	0.125	5	0.5	0.563	4.500	1	1.250	0	1.875	15.000
Clock (MHz)	T_{ck} (µs)	INPSAMPLE[1]	Ndelay[2]	T_{sample}[3]	T_{sample}/T_{ck}	INPCMP	T_{eval} (µs)	INPLATCH	T_{conv} (µs)	T_{conv}/T_{ck}
16	0.063	9	1	0.500	8.000	1	0.625	0	1.188	19.000
32	0.031	17	1	0.500	16.000	2	0.625	1	1.156	37.000

Figure 8 – ADC sampling and conversion timings (Bolero512K_RM_Rev7_07_2010.pdf - p. 731 – Table 26-1)

The ADC block proposes also a programmable analog watchdog. This function verifies if a conversion result belongs to a predefined voltage interval, set by the threshold registers THRH and THRL which define the upper and lower limits of the interval.

Several maskable interrupt are proposed. Several end-of-conversion interrupts are proposed: EOC (end of a conversion), ECH (end of conversion of a chain), JEOC (end of an injected conversion), JECH (end of injection chain), EOCTU (end of conversion in CTU conversion mode). Interrupts are also associated to the analog watchdog: WDGxL and WDGxH which indicates which thresholds have been crossed.
The ADC proposes two low-consumption modes: the power down and auto clock-off modes. The power-down mode is the nominal mode after reset. All the configurations of the ADC must be done in power-down mode. The conversion cannot start in power-down mode. If a power-down mode entry is requested while a conversion is on-going, the conversion must be completed before entering in low-power mode.
In auto clock-off mode, the ADC clock is switched off and no conversion can be performed.

2. ADC registers

a. Configuration of the pad

It is important to enable the I/O pad associated to an analog channel as an analog input. The APC bit of the PCR register associated to the pad must be set to ‘1’ (refer to part V – GPIO pad configuration).

b. Configuration settings of the ADC block

All the configurations of the ADC (conversion mode, power-down mode, start of conversion…) are provided by the Main Configuration Register (MCR). The configuration of the ADC must be done in low-power mode. The bit MODE selects if a scan mode or a one-shot mode is configured in normal mode. The bit NSTART starts a normal conversion. Writing a ‘1’ launches the conversion. The bit is set to ‘0’ at the end of the conversion. Writing a ‘0’ stops the current chain conversion. ADCLKSEL set the ADC clock frequency to the 1x or 1/2x the peripheral clock frequency. Writing a ’0’ to the PWDN bit forces the ADC to quit the power down mode to the IDLE mode. It is necessary to start conversions. Writing a ‘1’ is a request to enter in power down mode.

Address: Base + 0x0000 Access: User read/write

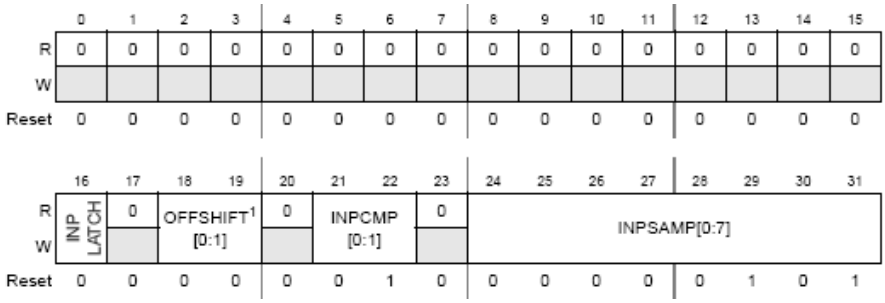
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	OWREN	WLSIDE	MODE	0	0	0	0	NSTART	0	JTRGEN	JEDGE	JSTART	0	0	CTUEN	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	0	0	0	0	0	ADCLK SEL	ABORT CHAIN	ABORT	ACKO	0	0	0	0	PWDN
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

The register Main Status Register (MSR) provides status of the ADC (normal conversion on-going, current conversion channel address, power-down mode…).

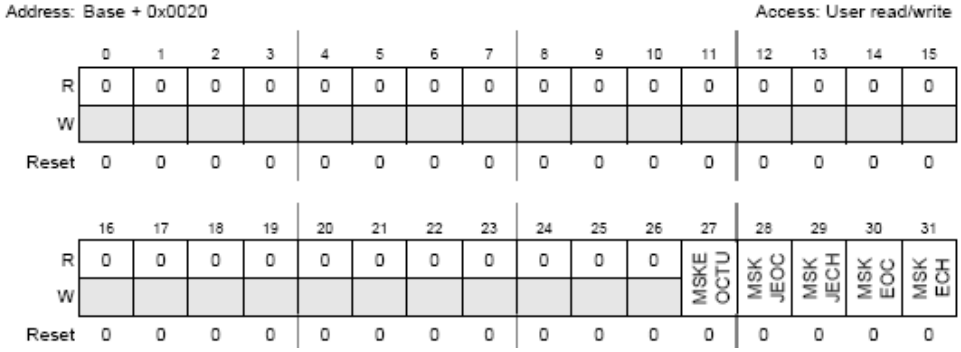
c. Conversion timing registers

Three Conversion Timing Registers are proposed: CTR[0] for internal precision channels (ANP[0] to ANP[15]), CTR[1] for internal standard channels (ANS[0]to ANS[15] and ANX[0] to ANX[3]), and CTR[2] for external multiplexed channels. See part 1 for the configuration of INPLATCH, INPCMP and INPSAMP fields.



d. Configuration of interrupts

Several registers are proposed to mask the maskable interrupts associated to the ADC block. The Interrupt Mask Register (IMR) enables End-of-Conversion type interrupts. The interrupts are enabled by writing '1' in register bits.



The register Interrupt Status Register (ISR) gives the interrupt flags associated to the maskable interrupt enabled by IMR register.

Interrupts can be associated to the end of conversion of each channel with the Channel Interrupt Mask Registers CIMR[0..2]. Precision channels are associated to register CIMR[0], standard channel to CIMR[1].

The register Channel Pending Register CEOCFR[0..2] gives the interrupt flags associated to the maskable interrupt enabled by CIMR register.

End of conversion interrupts are associated to interrupt vector number 62 (report to Table 10-10 p 253/956).

e. Selection of analog inputs

The selection of enabled analog inputs in a normal conversion chain is done with Normal Conversion Mask Register NCMR[0..2]: NCMR[0] for precision channels (ANP[0] to ANP[15]), NCMR[1] for standard channels (ANS[0] to ANS[15] and ANX[0] to ANX[3]). The configuration of this register must be done in low power mode. Writing a '1' in the bit corresponding to an analog channel selects this channel in the conversion chain. For example, if a normal mode is selected in Scan mode, if CH1 = '1' and CH7='1' only (all the other bit set to '0'), the following conversion sequence will be done continuously: sample/convert channel 1, sample/convert channel 7, sample/convert channel 1, sample/convert channel 7….

Address: Base + 0x00A4 Access: User read/write

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	CH15	CH14	CH13	CH12	CH11	CH10	CH9	CH8	CH7	CH6	CH5	CH4	CH3	CH2	CH1	CH0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The selection of injected channels is done with the JCMR[0..2] registers.

f. Power down configuration

As explained previously, the request of power down entry or exit is set with PWDN bit in MCR register. It is possible to configure the delay between the exit of power down mode and the start of the conversion with the Power Down Exit Delay Register (PDEDR).

g. Data registers

ADC conversion results are stored in data registers. There is one data register per analog channel. There are 96 Channel Data Register CDR[0..95]. CDR[0]to CDR[15]are associated to analog precision channels, CDR[32..47] to the standard channels. A CDR register is organized as follows: several bit to give a status of the conversion result, and the 10 bit conversion result (filed CDATA). The alignment of the data (right or left alignment) is set by the register WLSIDE in MCR register.

Address: See Table 26-5 Access: User read/write

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0	0	0	0	0	0	0	0	0	0	VALID	OVERW	RESULT[0:1]	
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	0	0	0	0	CDATA[0:9]									
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The bit VALID notifies if CDATA comes from a valid conversion. This bit is automatically cleared when the data is read. The bit OVERW notifies that the previous converted data has been overwritten by a new conversion. The field RESULT[0:1] reflects the conversion mode for the corresponding channel.

IX - E-MIOS blocks and PWM module

The eMIOS blocks (Configurable Enhanced Modular IO Subsystem) is dedicated to the measurement and the generation of timing events (e.g. capture/compare functions, generation of pulse width modulation (PWM) signals). In this part, only a basic presentation of the structure of the bloc will be provided and the configuration for PWM generation will be given.

Refer to Chapter 25 – Configurable Enhanced Modular IO Subsystem for more details about this block and the configuration of all the other functions.

1. eMIOS blocks presentation

The eMIOS block proposes several Unified Channels which can perform a list of timing measurement and generation functions, according to the software configuration. The hardware and the operation principles are detailed in Chapter 25 of the reference manual of MPC5604B, but most of them are out of the scope of this document.

The MCU contains two eMIOS blocks: E_MIOS_0 and E_MIOS_1. Each e-MIOS block is made of 28 unified channels, as shown in Fig. 9. Each unified channel is associated to an input/output (I/O) pad, as alternate function (called E0UC or E1UC in Table 2-3). Even if each channel is based on the same hardware architecture, 5 types of channel exist that differ from the offered function.

The clock of e-MIOs blocks is provided by the system clock that can be divided by a programmable prescaler. The operation of channels can be synchronized by internal counters (only for types G and X channels), or by counter buses driven by other channels. The counter and counter buses are 16 bit long. In this last mode, several channels can be synchronized. Five counter buses are shared by channels: A, B, C, D and E. Only type X channels can drive the counter buses. The counter bus A is the default counter bus used by every channels, it is driven by channel 23.

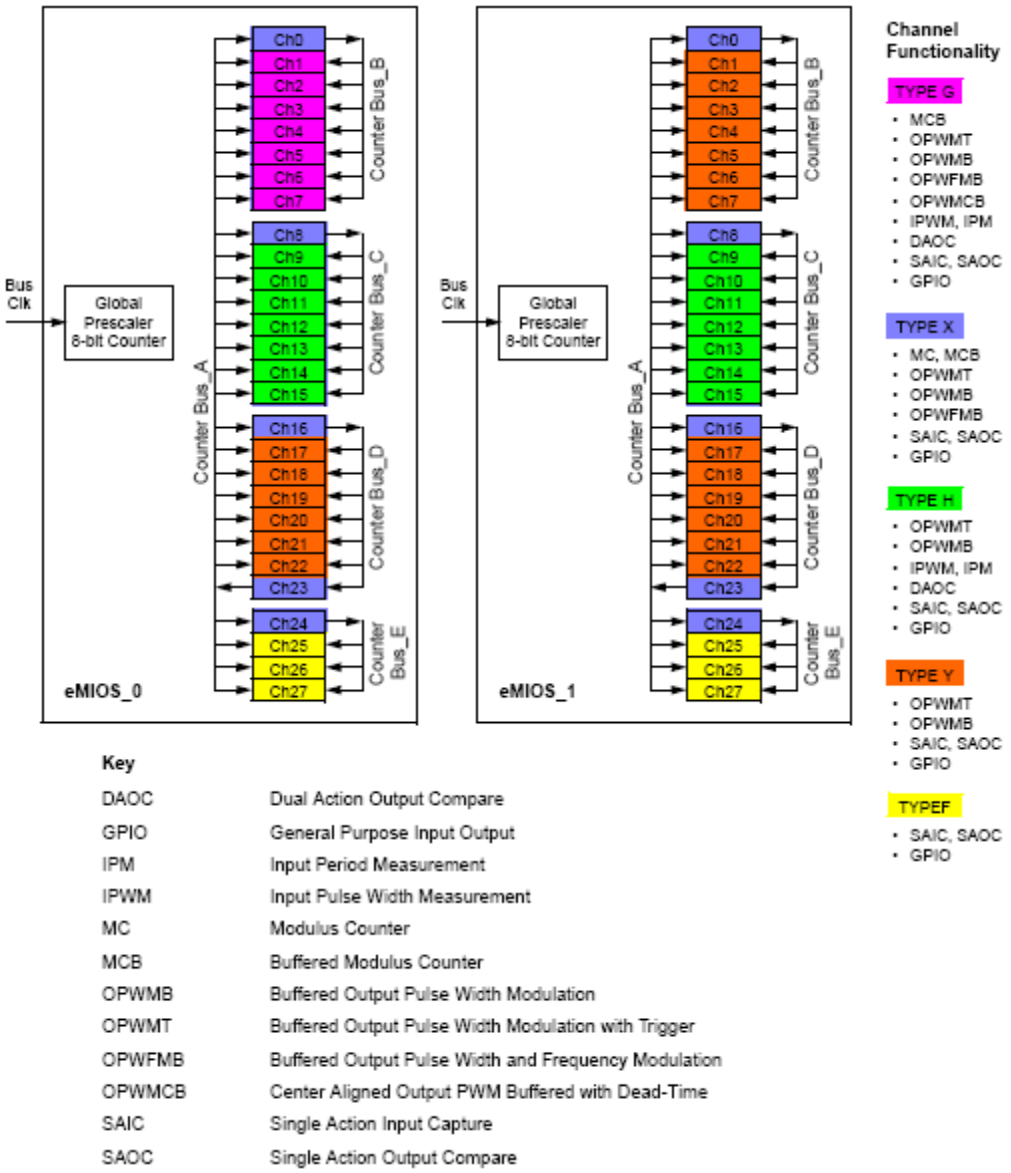


Figure 9 – eMIOS block organization (Bolero512K_RM_Rev7_07_2010.pdf - p. 676 – Fig. 25-1)

The unified channels propose up to 12 functions, that we will not detail. The functions are based on the same hardware, which is activated or not according to the user-defined software configuration. The default function is GPIO. This mode is required when the configuration of e-MIOS channel has to be changed.

The basic operation of the channel relies on a counter that increments or decrements an internal value, and two readable or writable internal registers (called A and B). Their respective roles depend on the selected mode. When some predefined events arise, the counter can be stopped, its content can be written in register, flags can be raised and/or an flip-flop connected to the output pad can be toggled. For example, in input capture mode, when a rising or falling edge arise on an input signal, the value of the internal counter is written in register A and the counter internal value is reset to 0.

Second example: in PWM mode, two values are written in registers A and B. They define the waveform of the PWM signal (period, duty cycle, leading and trailing edges position). Each time the counter value matches with register A or B content, a flag can be raised and the output flip-flop state is changed.

Unified channels propose 4 PWM generation modes:

- Buffered Output Pulse Width Modulation (OPWMB): basic PWM generation mode. The configuration sets the placement of leading and trailing edges of the PWM signal in a given period. Every PWM generation mode is double buffered, i.e. each time you change the period or the duty cycle parameters, the transition is smoothed. The new parameters are taken into account only at the end of a PWM period.
- Buffered Output Pulse Width Modulation with Trigger (OPWMT): in this mode, several PWM channels can have the same leading edge position, but different trailing edge.
- Buffered Output Pulse Width and Frequency Modulation (OPWFMB): in this mode, both the frequency and the duty cycle can be changed.
- Centered aligned Output PWM Buffered with Dead Time (OPWMCB): the leading and trailing edge appears after and before the beginning and the end of a period.

2. PWM configuration

In this part, we will present only the basic configuration of OPWMB mode.
PWM mode requires an I/O pad, so that the PCR register of this I/O pad must be carefully configured (refer to part V of this document). The alternate function has to be selected by the PA bit field. It is not necessary to activate the output or the input buffer of the I/O, since the pad is connected to the output flip-flop of the unified channel.
First, the e-MIOS block has to be configured, by the Module Configuration Register MCR (p. 678). Setting the bit MDIS ensures the entry in low power mode of the e-MIOS block. The GPRE[0:7] field configures the e-MIOS block clock frequency by setting the prescaler value. The e-MIOS clock frequency is equal to the system clock frequency divided by GPRE+1. The e-MIOS clock prescaler and internal clock are enabled if bit GPREN is set. The bit GPBE enables the global time base and the internal counter operation. Setting the bit FRZ ensures that the internal counters of unified channels will be stopped when the MCU enters in debug mode.

Address: eMIOS base address +0x00

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	MDIS	FRZ	GTBE	0	GPREN	0	0	0	0	0	0	0	0	0	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	GPRE[0:7]								0	0	0	0	0	0	0	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Then, the configuration of each used unified channel has to be done, with the registers UC Control Register (CCR), UC A and B registers (CARD and CBDR, which are 16 bit registers). The bit field MODE[0:6] configures the function of the channel. The BSL[0:1] selects the counter source (internal or counter buses A, B, C, D or E). The bit EDPOL determines the polarity of the PWM signal. UCPREN an UCPRE[0:1] enables a channel prescaler to divide the counter frequency.

Address: UC[n] base address + 0x0C

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	FREN	0	0	0	UCPRE[0:1]		UCPREN	DMA	0	IF[0:3]				FCK	FEN	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	0	0	0	BSL[0:1]		EDSEL	EDPOL	MODE[0:6]						
W			FORCMA	FORCMB												
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Let's detail the configuration of OPWMB mode. First, the period of the PWM channel is defined by the time required by the counter to count from 0 to the maximum value of the counter. The counter can be provided by another unified channel configured in Modulus Counter Buffer mode (MCB) which drives a counter bus. The MODE[0:6] of this channel is set to 0x50. A channel able to drive a counter bus has to be chosen. This channel is synchronized by an internal counter, so that the BSL[0:1] field is set to 0x3.
Secondly, the PWM mode and the origin of the counter (a counter bus) of the channel have to chosen. The MODE[0:6] of this channel is set to 0x60 and the BSL[0:1] to 0x00 if Counter bus A is selected, or to 0x01 if another counter bus is selected. Then, the values of registers A and B have to be configured. In OPWMB, the registers A and B of a channel set the leading and trailing edge positions respectively in the PWM signal period. If the maximum count value is set to 1000 and the register A value is set to 500, the leading edge will appear at mid-period. Finally, the polarity of the PWM signal is set with the bit EDPOL, i.e the leading edge is a rising or falling edge.

X - Cross Triggering Unit (CTU)

Refer to Chapter 27 – Cross Triggering Unit for the configuration of this module.
This module aims at synchronizing the conversion of Analog to Digital Converters (ADC) on timing events from eMIOS or PIT blocks. The advantage of the CTU is that it can trigger the ADC faster than an interrupt request.
The following figure presents the block diagram of the CTU module.
When a timing event occurs and is transmitted to one of the 64 trigger inputs of the CTU block, an analog-to-digital conversion is triggered by the CTU. The number of the ADC channel to be converted is provided by the field CHANNELVALUE of the register EVTCFGR[n], with n the number of trigger input.

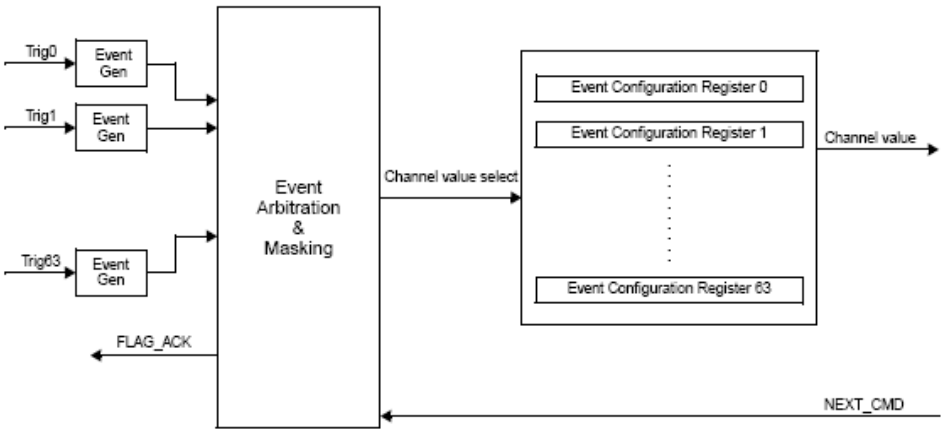


Figure 10 – CTU block diagram (Bolero512K_RM_Rev7_07_2010.pdf - p. 769 – Fig. 27-1)

The assignment between eMIOS output and CTU trigger inputs is given by table 27-4 (p. 772). The configuration of the trigger input number n is given by the register EVTCFGR[n]. The bit TM masks or enables the trigger. CHANNEL VALUE indicates the ADC channel to be converted (refer to table 27-5 p. 774). When a trigger occurs on one trigger input, the bit CLR_FLAG of the register is set to '1'. This flag has to be cleared to acknowledge the triggering. For trigger from eMIOS, the flag clearing is automatically done by CTU module. However, for trigger from PIT, the flag must be cleared by software by writing a '1'.

Address Offset: 30h-12Ch Reset value: 0000_0000h

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	TM	0	0	0	0	0	0	0	CLR_FLAG[1]	0	CHANNEL_VALUE[5:0]					
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

One possible application is to generate a PWM signal with the eMIOS block to drive a motor and use the CTU to make an analog-to-digital converter instantly, e.g. to measure the consumed current.

XI - Periodic interrupt Timer (PIT)

Refer to Chapter 31 – Periodic Interrupt Timer for the configuration of timer.

The MCU MPC5604B proposes several timer peripherals dedicated to different uses:

- System Timer Module (STM): it contains a 32 bit running-up counters clocked by the MCU system clock and four 32 bit compare channels with individual interrupts. This block is dedicated to the measurement of code execution time (number of clock cycles).

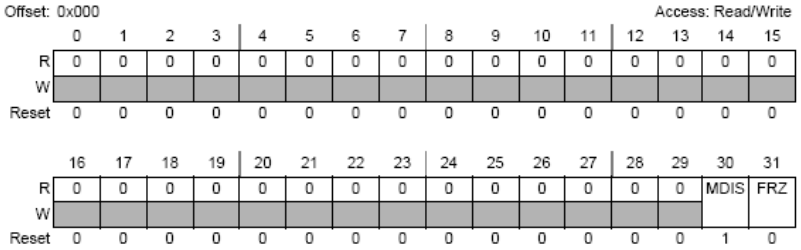
- Periodic Interrupt Timer (PIT): programmable timers for general purpose time measurements

- Real Time Clock / Autonomous Periodic Interrupt (RTC / API): the RTC is a free counter independent of the operation mode (run or low power mode) used to measure predefined time interval. The RTC contains a 32 bit counter driven either by SIRC, SWOSC or FIRC internal oscillators (see chapter III of this document, Clock Generation Description). It also contains a 10 bit compare channel, able to produce periodic interrupts (API block). The main interest of the API block is to generate periodic wakeup requests to exit from low power mode, or periodic interrupt requests.

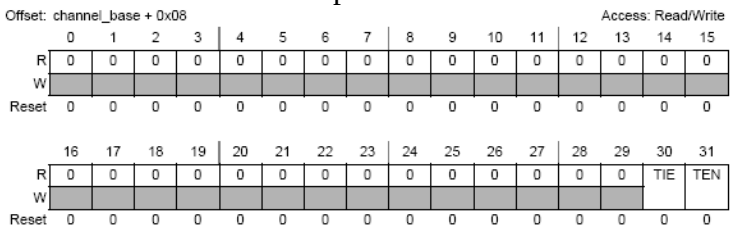
- Software Watchdog Time (SWT): it contains a 32 bit timer used to prevent from system lock-up when the software is trapped in a loop or a bus transaction failed.

Only PIT and SWT will be detailed. SWT will be presented in the next chapter.

The PIT block is an array of 6 programmable timers that can trigger maskable interrupt request each time they reach '0'. These 6 timer channels are called PIT.CH[0] to PIT.CH[5]. They are associated to 32 bits downcounters.
The general configuration of PIT block is set by the register PITMCR. The bit FRZ ensures that the timers are stopped in debug mode when set. Setting the MDIS bit to '0' enables the clock for the timers.



The configuration, the count value charging and the interrupt flag are provided by several registers for each timer channel PIT.CH[n], n = 0..5. The register LDVAL configures the timer start value and thus the timeout period of the timer (depending on the timer clock period). Writing a value in this register does not restart the timer. The timer has to be disabled first and then enabled again. The value is loaded in the timer counter (its current value is indicated by the register CVAL, only in read mode) at the each time-out (i.e. each time it reaches 0). The individual configuration of each timer channel is set by the register TCTRL. Setting the bit TEN loads LDVAL value in the timer counter and starts the downcounting operation. Setting the bit TIE enables interrupt raise each time the timer counter reaches 0.



The bit TIF of the register TFLG is set to 1 when the time-out of the timer channel occurs. If the interrupt associated to time-out of the channel is enabled, the TIF causes an interrupt request. To reset the TIF bit, a '1' has to be written. Six maskable interrupt requests are associated to PIT block, for each timer channel. Timer channels 0, 1 and 2 interrupts are associated to interrupt vector numbers 59, 60 and 61. Timer channels 3, 4 and 5 interrupts are associated to interrupt vector numbers 127, 128 and 129 (report to Table 10-10 p 253/956).

XII - Software Watchdog Timer (SWT)

Refer to Chapter 28.2 – Software Watchdog Timer (SWT) for the configuration of this module.
The SWT peripheral contains a 32-bit down timer clocked by the 128 KHz SIRC oscillator. It aims at checking the MCU operating status and forces it to reset if the embedded software is trapped in a loop or if a bus transaction fails to terminate. This is a fundamental block to improve the operation safety of a MCU. When this module is enabled, the internal counter counts down. The running program is supposed to reset the timer before the time-out of the timer. Otherwise the SWT generates either a reset or an interrupt, depending on the user configuration.
In debug mode, the SWT is always frozen. However, in nominal operation, it is enabled by default and the time-out value is 10 ms. If the SWT is not disabled or if a software procedure has not been developed to reset the SWT regularly, the MCU will reset after 10 ms.
In this part, we only give the code lines used to disable the SWT:

```
void disableWatchdog(void) {
  SWT.SR.R = 0x0000c520;     /* Write keys to clear soft lock bit */
  SWT.SR.R = 0x0000d928;
  SWT.CR.R = 0x8000010A;     /* Clear watchdog enable (WEN) */
}
```

XIII - CAN bus and FlexCAN module

This chapter aims at providing some elements about hardware architecture, operation principles, frame format, bit time structure of CAN bus, but also the more basic programming elements for the embedded CAN controller of the MPC 5604B, called FlexCAN.

The Controller Network Area (CAN) bus is a serial bus widely used for automotive applications and dedicated to the communications between command entities, sensors and actuators of the vehicle. The bus has been developed by Bosch initially, in order to propose a real-time communication protocol dedicated to distributed systems and satisfying numerous requirements (robustness to electromagnetic interferences and errors, reliability…). Bosch created a consortium of system and circuits manufacturers in order to standardize the bus. The standard was born is 1991 and takes the name IEC 11898. It defines only the physical and data link layers (layers 1 and 2 according to ISO/OSI representation of communication systems) but no recommendations are given for the application layer.
CAN bus has several key advantages for automotive applications:

- It is a serial bus with a reduced number of wires (maximum 4 wires)
- It can interconnect a large network of sensors, command devices and actuators (up to 2048 devices for CAN 2.0A protocol)
- The network architecture does not rely on a central controller, the network rus in multi-master mode, i.e. all the stations listen the frames emitted on the network continuously and can transmit at any moment
- The bus access arbitration is non deterministic (the stations generate messages and try to access to the bus randomly) and *Carrier Sense Multiple Access/Bitwise Arbitration* (CSMA/BA) type. When several stations try to access to the bus simultaneously when

the bus is idle, the transmission is aborted and is reinitiated after a random period in CSMA/CD (Collision Detect) protocol. In CAN bus, a priority level is assigned to every message through several transmitted bits in order to prevent from bus access conflict.

- The physical transmission can be done either on a twisted pair, an infrared, a radio link, optic fiber… The standard does not prescribe the physical medium for the bus.
- Several error detection methods are proposed by the protocol (CRC, simultaneous survey of the bus by all the stations, use of stuffing bits) in order to minimize the error probability (up to 4.6e-11 according to some car manufacturers).

1. Hardware architecture of CAN bus

The figure shown below describes the typical architecture of CAN bus. The stations are bidirectional and are interconnected by the bus (here through a twisted pair). The stations are usually made of 3 parts:

- CAN controller: it is the central part of a CAN station. It manages the protocol and is usually embedded in a MCU. The CAN controller has a reception digital input RX and a transmission digital output TX, which are not directly connected to the transmission medium.
- A MCU for the application layer. The standard IEC11898 does not give any recommendations about the application layer.
- An external component called CAN transceiver for the interface between the CAN controller and the transmission medium. The CAN transceiver aims at shaping the electrical signals.

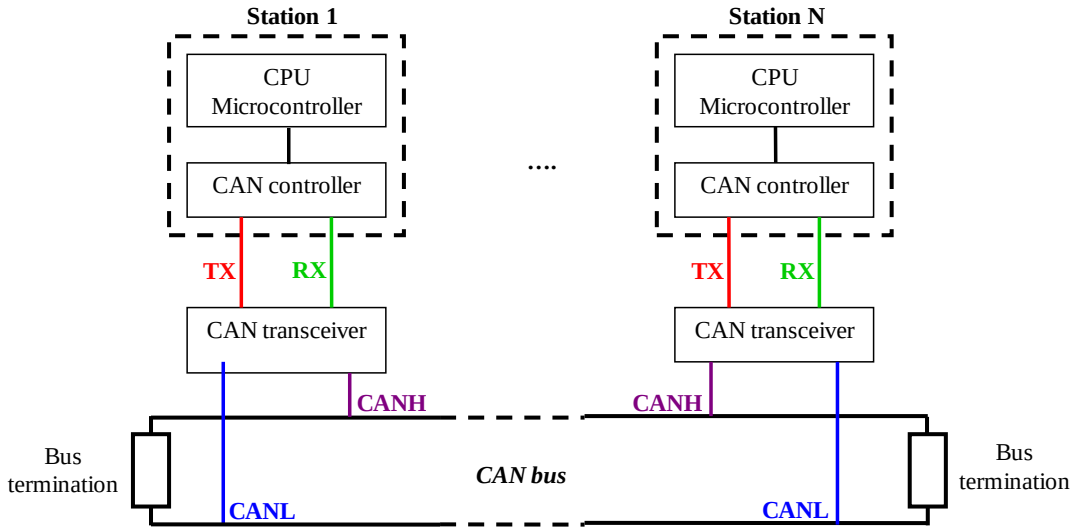


Figure 11 – Typical hardware architecture of a CAN bus

The CAN bus is differential in order to reduce the impact of electromagnetic emissions. For a twisted pair, the line must have a 120 Ω characteristic impedance. Two signals with different electrical level are transmitted: CANH and CANL as shown in the figure below.

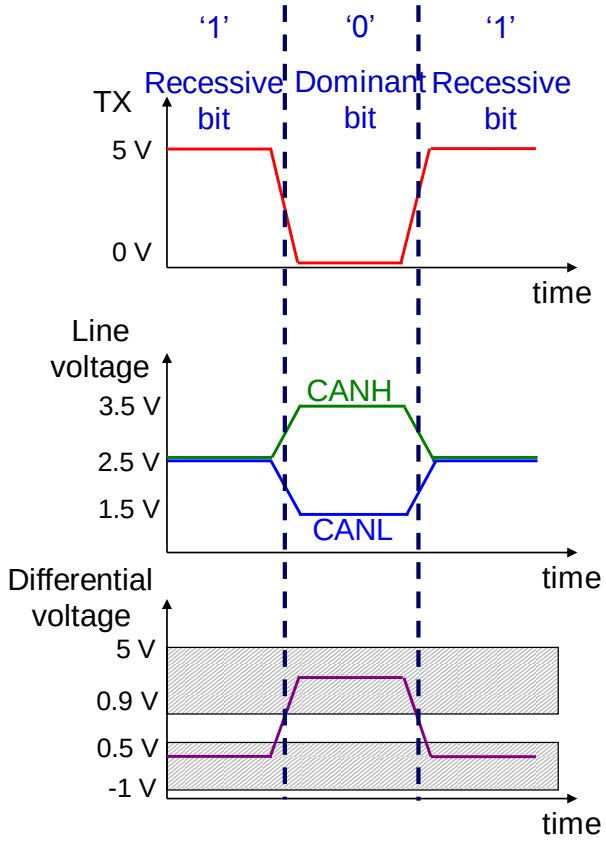
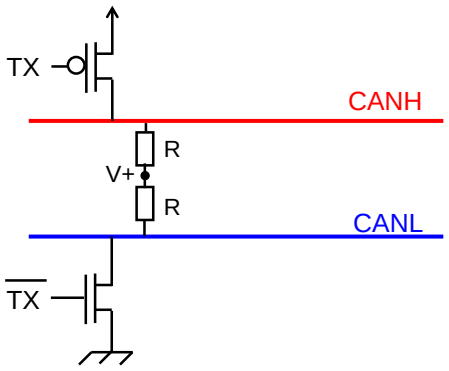


Figure 12 – Electrical signal on a CAN bus

The transmitted signal along the CAN bus is binary with states '0' and '1'. These states have different priorities: '0' is the dominant state while '1' is recessive. This is the bus state in idle mode. The principle of the access arbitration is based on this difference. The connection of the different stations connected to the bus is based on a wired AND function.



The MCU MPC5604B integrates a complete CAN module called FlexCAN (see Chapter 22 – FlexCAN). On the development kit TRK-MPC5604B, the CAN transceiver is embedded in the System Basis Chip SBC (reference MCZ33905S5EK). This component will be used in Debug mode. You must force the component to enter in this mode by following the procedure described in part 5.

2. Format of data frames

Several types of frames can be propagated along the CAN bus. Only data frames are described in this document, remote and error frames will not be described. Figure 11 presents the format of data frames, according to CAN 2.0A and 2.0B specifications. Only the frame defined by CAN 2.0A specification is presented here. The CAN 2.0B is similar, except the address field extended to 29 bits to offer a larger number of stations on the network.

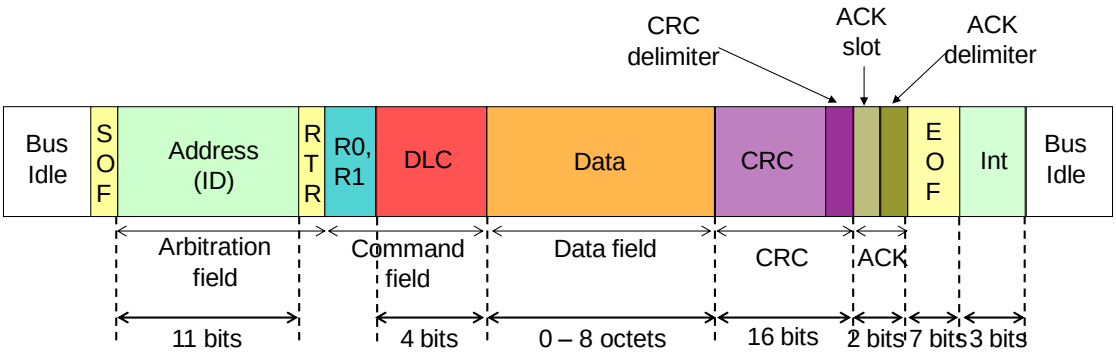


Figure 13 – Format of data frame (CAN 2.0A specification)

The frame is composed of the following field:

- Start of Frame bit (SOF): dominant bit emitted by any station that wants to transmit a data frame. Once this bit is emitted, no other station will try to transmit.
- The address or frame identifier (ID) field composed of the 11 bits (or 29 bits in CAN 2.0B specification) of the frame and the RTR bit (to indicate a Remote Transmission Request frame). This field is used to determine which station is allowed to transmit. The priority is given to the station with the ID field which starts with the largest number of dominant bit (bit '0'). This field is not always used to identify the addressee of the message. The CAN standard does not give any recommendations about the construction of identifiers.
- The RTR bit indicates if the frame type is data or remote frame.
- The control field is composed of 2 reserved bits R1 and R0 for future extension of the CAN standard. R1 can be used as IDE bit (Identifier Extension) in order to indicate if the frame is in standard format. The 4 following bits are the Data Length Code (DLC) field which provides the octet number of the data field within the transmitted frame.
- The data field can be 0 to 8 octet long. MSB is transmitted first in each octet.
- The CRC field (Cyclic Redundancy Code) is made of 15 bits and one delimiter bit. The coding is BCH type (Bose-Chaudhuri-Hocquenghem).
- The acknowledgment field is made of 2 bits. The emitter station transmits 2 recessive bits. During the reception of the first bit (called Acknowledgement Slot), all the other stations connected to the bus which have received a valid message must transmit a dominant bit. The emitter station receives a dominant bit if at least one station have receive a valid message. If one station has received an invalid message, it must transmit an error frame.
- End of Frame (EOF): this field is composed of 7 recessive bits and notifies the end of the frame.
- Interframe bit: it is a separator between 2 successive frames. It is composed of 3 recessive bits.

At the end of the frame emission, the bus enters in IDLE mode. By default, the bus state is recessive.

3. Bit time and data synchronization

The transmission of digital information requires a correct reading and interpretation of the received signal. The sample point of the received signal must be defined precisely. The choice of the sample point relies on a compensation of:

- the delay introduced by the signal propagation along the bus and through the electronic devices
- the delay induced by arbitration and acknowledgment phases required by the protocol.
- All the other source of variability of binary period (such as jitter on clock signal, loss of synchronization)

The CAN standard proposes an organization of the bit time in several time segments in order to define an optimal sample point.

a. Construction of the bit time

The CAN standard has defined a precise construction of the bit time in several segments in order to compensate signal propagation delay, ensure receptor synchronization on incoming bit stream and resynchronization of the receptor in case of variation of the clock frequency of one station. All the stations must operate with in-phase binary clocks which have exactly the same frequency. However, these clocks are built from the fastest clock within the system, which is not shared by all the stations.
CAN standard define a bit time from a time base called *minimum time quantum*. It is the smallest time elements considered by a station. In case of a CAN controller embedded in a MCU, the minimum time quantum is equal to the CAN controller bus period. The time quantum Tq is defined from this minimum time quantum and sets the time unit to build the bit time.
The bit time is divided in 4 different segments, defined by an integer number of time quantum.

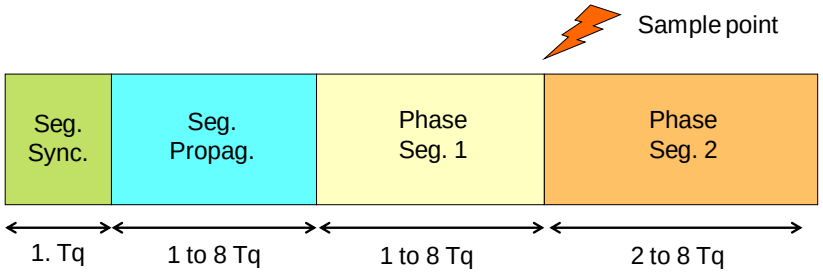


Figure 14 – Structure of a bit time and organization in time quanta

b. Synchronization segment

This segment is always equal to 1 Tq. This segment is associated to the detection of a bit. If the receptor is synchronized on the received signal accurately, the incoming binary transition will coincide with the bit start forecast by the receptor. However, this is not true in practice, due to loss of synchronization between the different stations connected to the bus. But the CAN standard proposes some *tricks* to resynchronize the receptor and adjust the sample point.

c. Propagation segment

The signal propagation along the bus is not instantaneous. There is a certain delay due to the finite propagation speed of the signal and the line mismatch issues. Moreover, the electronic devices of the CAN transceiver introduce a significant delay. The binary signal setting is delayed and so that a minimum bit time must be respected.

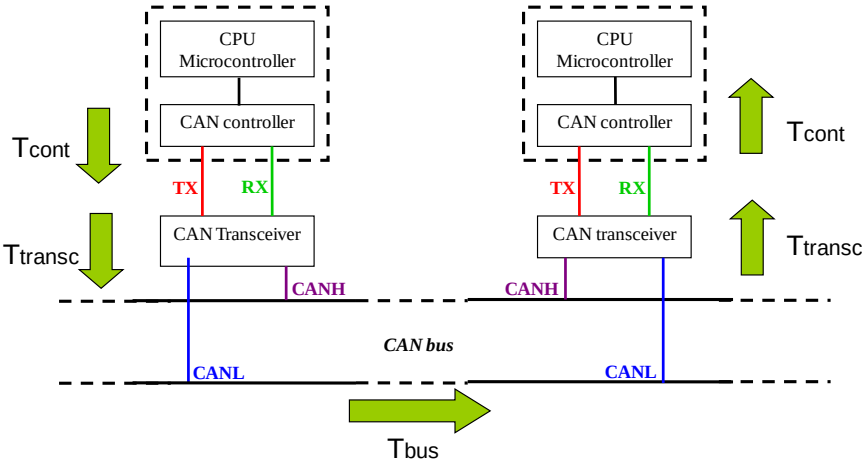


Figure 15 – Delay induced along the CAN bus

The propagation segment aims at compensating these delays. The method suggested by the CAN standard to define a correct value for the propagation delay consists in considering the worst case situation: 2 stations separated by the longest cable length. The first station transmits a recessive bit which propagates to the second station. Before this bit arrives, the second station emits a dominant bit, which forces the bus in dominant state after a certain delay. This dominant bit propagates to the first station. As soon as the first station receives the dominant bit, it loses the bus arbitration immediately. The arbitration is ensured only if the propagation segment duration is larger than the sum of all the delay, i.e the round trip time of the signal.

$$T_{seg\ propag} > 2 \times \sum delay$$

d. Resynchronization – Phase errors and resynchronization jumps

Before explaining the roles of phase segments Phase Seg. 1 and 2, we have to introduce how CAN receptors are resynchronized. CAN transmission type is asynchronous (the bus clock is not transmitted). The clock of the receptor is synchronized on the incoming binary stream (from the binary transitions).
The CAN stations have different clock reference and are separated by long cables (up to hundred of meters). In these conditions, a perfect synchronization cannot be guaranteed between every station. Two mechanisms are defined by the CAN protocol for the resynchronization and are not applied simultaneously:

- Hardware synchronization: the rising edge instant of the incoming binary signal is compared to the on-going bit time. If these instants are different, the bit time starting is modified and synchronized on the incoming bit.
- Resynchronization bit time: this is a software method dedicated to the compensation of phase error, i.e. the gap between the actual rising edge of the incoming bit and its forecast position. This phase error is introduced by the variations of frequency of each CAN controller of the stations connected to the bus.

The following figure describes the concept of phase jumping. If the phase error remains small, its effect can be compensated only by readjusting the position of the resynchronization segment: a resynchronization jump is done. However, this jump is limited by the

Resynchronization Jump Width (RJW). It is expressed in Time quanta, and ranged from 1 to 4 Tq.

If $|e| \leq RJW$, then the resynchronization is similar to a hardware synchronization.

If not, the resynchronization consists in modifying the time intervals Phase Seg. 1 and Phase Seg. 2 in order to resynchronize the bit time and readjust the sample point:

- If e > RJW, the rising edge of the incoming bit falls into the propagation segment or segment phase 1 of the current bit. The position of sample time is readjusted by increasing the duration of segment phase 1.
- If e < -RJW, the rising edge of the incoming bit falls into the propagation segment or segment phase 2 of the previous bit. The position of sample time is readjusted by increasing the duration of segment phase 2.

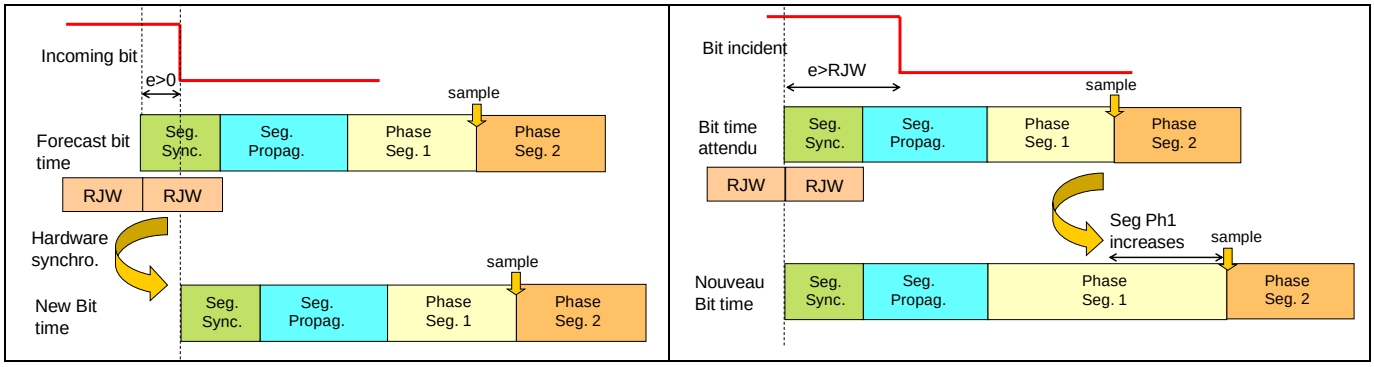


Figure 16 – Resynchronization mechanisms (left: hardware, right: bit time)

e. Phase segments 1 et 2

After the description of resynchronization mechanism, we can detail how to configure segments Phase 1 and Phase 2. Their duration depends on RJW, which must be computed. RJW aims at compensating the clock frequency drift of every stations. This effect is linked to internal oscillator (effect of temperature, process dispersion) or frequency drift linked to frequency modulation of the clock source for example. For example, the error on clock period is expressed in percent as *Error* and is the sum of the tolerance of the resonant frequency of quartz and the other source of error such as the frequency modulation applied on the clock. The clock period varies between:

$$T_{CLK\_NOM}\left(1-\frac{Error}{100}\right) < T_{CLK} < T_{CLK\_NOM}\left(1+\frac{Error}{100}\right)$$

The maximum variation of a bit time is equal to $\Delta T_{bit\,\max} = T_{bit\_nom} \times \frac{Error}{100}$. The resynchronization jump must compensate the worst case clock frequency variation, which occurs when the clock period varies between both extreme values between 2 consecutive bits:

$$RJW \geq 2 \times \Delta T_{bit\,\max} = 2 \times T_{bit\_nom} \times \frac{Error}{100}$$

CAN standard defines another worst case situation: 29 identical bits are transmitted successively. The CAN receiver does not detect any edge transition and desynchronization can occur due to oscillator drift. The CAN standard prohibits that more than 29 successive identical bits are transmitted. With this worst case situation, the resynchronization jump must be equal to:

$$RJW \geq 29 \times 2 \times \Delta T_{bit\,\max} = 58 \times T_{bit\_nom} \times \frac{Error}{100}$$

When the bit time is resynchronized, Phase_Seg1 always increases and Phase_Seg2 always decreases. A minimum duration of 1 Tq must be ensured for Phase_Seg1. Phase_Seg2 must be equal or larger than RJW to prevent hard synchronization forces the synchronization segment of the next bit time at the sample point of the previous bit. Moreover, the standard suggests to let at least 2Tq after the sample point, and the sum of Phase_Seg1 and Phase_Seg2 must not exceed 8Tq.

4. FlexCAN module

Refer to Chapter 22 – FlexCAN for the configuration of this module. The MPC5604B contains 3 FlexCAN modules, called CAN_0, CAN_1 and CAN_2. The FlexCAN module implements CAN protocol according to CAN 2.0B specifications. The data length can reach up 8 bytes and the data rate up to 1 Mbits/s.

a. General presentation of the module and message buffers

The block diagram shown below describes the structure of FlexCAN module. SRAM memories are dedicated to the storage of message (Message Buffer storage) and the ID of mask storage registers. Up to 64 messages can be stored. Each of these 64 Message Buffers stores configuration and control data, time stamp, message ID and data to be set or received. The 64 buffers of a FlexCAN module are called BUF[0] to BUF[63].

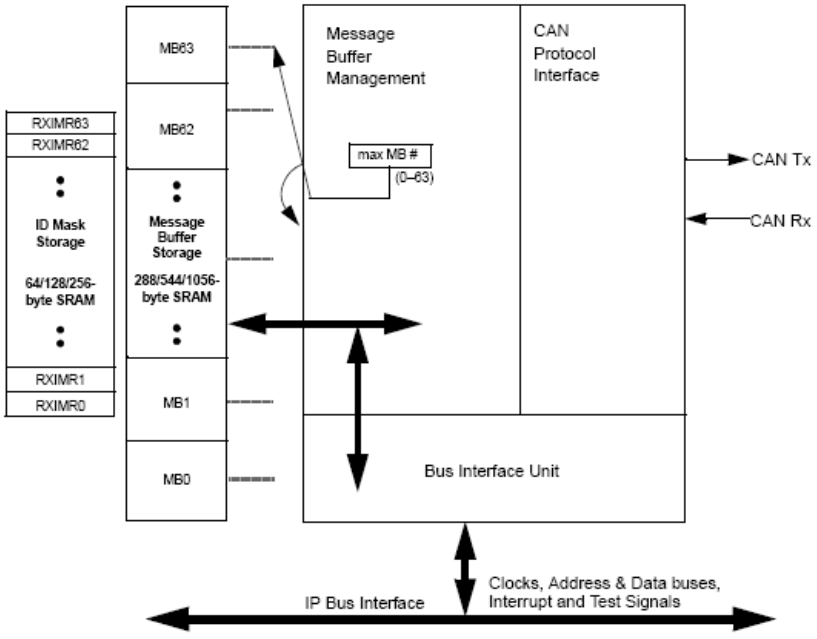


Figure 17 - Block diagram of FlexCAN module (Bolero512K_RM_Rev7_07_2010.pdf - p. 599)

Moreover, the 8 first Message Buffers can be configured to offer a FIFO reception structure. The FIFO reception operation is not detailed in this document. FlexCAN is made of 3 submodules:

- The CAN Protocol Interface manages the serial communication of the bus, the reception and transmission of the messages, the validation of received message and the error handling

- The Message Buffer Management manages the selection of Message Buffer for transmission and reception
- The Bus Interface Unit controls the access to the internal bus for the connection with the CPU. The Bus Interface Unit receives the clock and the data to transmit from the CPU and provides received data and interrupts.

The clock of the module can be derived from the bus clock or the quartz oscillator. Maskable interrupts are generated at each reception or transmission of a message.

We detail now how works the reception / transmission of the messages rapidly. In reception mode, the 64 Message Buffers works as a mailbox. The 64 message buffers are characterized by programmable IDs. The Message buffers store any frames which have the same ID, i.e. match. In transmission mode, an arbitration algorithm decides the prioritization of message buffers to be transmitted. The prioritization is based on the message ID (+ 3 prioritization bits PRIO for local priority) or the message buffer ordering according to the FlexCAN module configuration. The arbitration of the prioritization of message buffer transmission is described in the Transmission process part.
Figure 16 presents the structure of a Message Buffer. The buffer supports extend or standard frames (29 or 11-bit identifier).

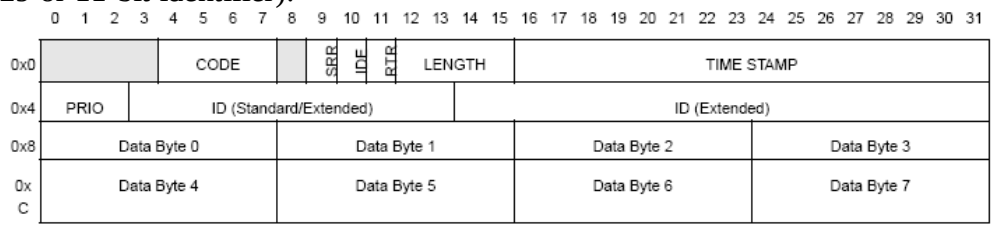


Figure 18 – Message buffer structure (Bolero512K_RM_Rev7_07_2010.pdf - p. 604)

The CODE field can be accessed by the CPU or by the module FlexCAN. It indicates the status of the Message Buffer and if it is in reception or transmission mode. Refer to tables 22-5 and 22-6 (p 605) for the encoding of Message Buffers. The user or the module changes this field to indicate that a message can be sent or a message has been sent. During transmission in Extended mode, the bit SRR must be set to '1'. The bit IDE identifies the frame format (Extended or Standard). The bit RTR set to '1' indicates that the Message Buffer has to transmit a Remote frame.
The field Length gives the length of the data (up to 8 bytes). The TIME STAMP is a copy of the free running counter embedded in the FlexCAN module (not detailed in this document). PRIO field gives a local priority to the Message Buffer in transmission mode (if LPRIO_EN bit is set in MCR register). The ID field is used for frame identification. In standard mode, only the 11 first bit are considered. The 8 DATA bytes contain the data to be transmitted or the Data received.

b. Principle of the configuration of the FlexCAN module

The software configuration of the FlexCAN module follows this procedure:

- Configuration of I/O pads
- Configuration of control registers of FlexCAN module
- Timing configuration (binary period and segments)
- Configuration of the interrupts
- Configuration of error management
- Configuration of operation mode

Refer to part 22-5. « Initialization/Application information » p. 642 for more information about the programming of the FlexCAN module.

c. Configuration of I/O pads

Two I/O pads are used for one CAN bus: a TX output and a RX input. TX and RX are alternate functions of several I/O pads. You can refer to Table 2-3 p. 45 to have a detail of the alternate functions of each I/O pad of the MCU.
Digital pads must be configured for TX and RX pins. It is recommended to configure TX as a open-drain output, with a medium or fast option. The RX must be configured as a digital input. For some pins, several CAN RX can be routed (e.g. on PC11, CAN1RX and CAN4RX are routed). It is necessary to define which CAN RX will be connected to the pad by the PSMI registers (see chapter SIUL).

d. Configuration of the control registers

Two registers provide the general configuration of the FlexCAN module: the Module Configuration Register (MCR) which sets global configurations of the module, and the Control Register (CR) which controls CAN bus features of the module (some of the bits of CR registers are detailed in timing configuration).
Let's start with the MCR register. This register can only be changed when the FlexCAN module is in Freeze mode.
Clearing the MDIS bit enables the FlexCAN module. Setting the FRZ bit enables the module to enter in Freeze mode in Debug mode or when HALT bit is set. The bit NOT_RDY indicates if the module is in Freeze or Disable mode. FRZ_ACK indicates if the module is in Freeze mode.

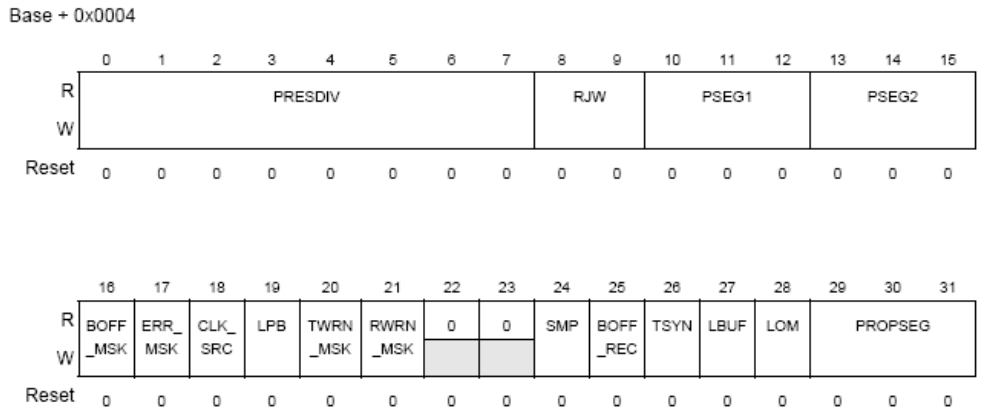
Base + 0x0000

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	MDIS	FRZ	FEN	HALT	NOT_ RDY	0	SOFT _RST	FRZ_ ACK	SUPV	0	WRN_ EN	LPM_ ACK	0	0	SRX _DIS	BCC
W																
Reset	Note[1]	1	0	1	1	0	0	Note[2]	1	0	0	Note[3]	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	LPRIO _EN	AEN	0	0	IDAM		0	0	MAXMB					
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

The WRN_EN bit enables Warning interrupts (in TX or RX) (See error counters for more detail about warning). The LPM_ACK indicates if the module is in Disable mode. Clearing the bit SRX_DIS enables the self reception, i.e. if a FlexCAN module is allowed to receive a frame that it transmits. The BCC bit allows the backward compatibility, i.e. a compatibility with previous implementation of CAN module in older MCU. In previous modes, the masking of identifiers cannot be done on individual Message Buffer. If the BCC bit is cleared, the previous implementation is allowed and the masking is ensured by the registers RXGMASK, RX14MASK and RX15MASK.
The LPRIO_EN enables the local priority to extend the ID during arbitration process. The local priority is given by the field PRIO of the Message Buffer. The AEN bit enables the abort of a transmitted frame. The MAXMB indicates the maximum number of Message Buffer used in the arbitration and matching processes.

Some details are now given about the CR registers (not the bit about timing configuration: RJW, PSEG 1 and 2, and PROPSEG, and the interrupt enabled bits). The bit CLK_SRC selects the CAN clock source, either from the crystal oscillator, or the bus clock. The clock source is then divided by a prescaler, configured by PRESDIV. The resulted clock is used to define the Time quanta. The bit LPB enables the loop-back mode (internal loop-back for test). The bit SMP configures the type of sampling (one or three point). The bit LBUF defines the ordering mechanism for Message Buffer transmission. The LOM bit enables the Listen-only mode.



e. Configuration of bit time

The CAN bus bit-rate depends on the CAN module clock, derived from the CAN clock source (bit CLKSRC) in CR register, and the division factor of the prescaler defined by the field PRESDIV. The binary period or bit time is divided in several segments given in Time quata Tq, according to:

$$bit\ time = \frac{\text{Pr}escaler\ value}{F_{CLK}} \times \left(\text{Pr}op\_Seg + Time\ Segment1 + Time\ Segment2\right)$$

$$bit\ time = T_q \times \left(\text{Pr}op\_Seg + Time\ Segment1 + Time\ Segment2\right)$$

The different segments are configured by CR register. The field PROPSEG defines the propagation segment time according to: $propagation\ segment\ time = T_q \times (+ PROPSEG)$.

The resynchronization jump is given by the 2 bit field RJW (from 0 to 3Tq). The fields PSEG1 and PSEG2 define the lengths of Phase segment 1 and 2 (from 0 to 7 Tq).

f. Interrupt configuration

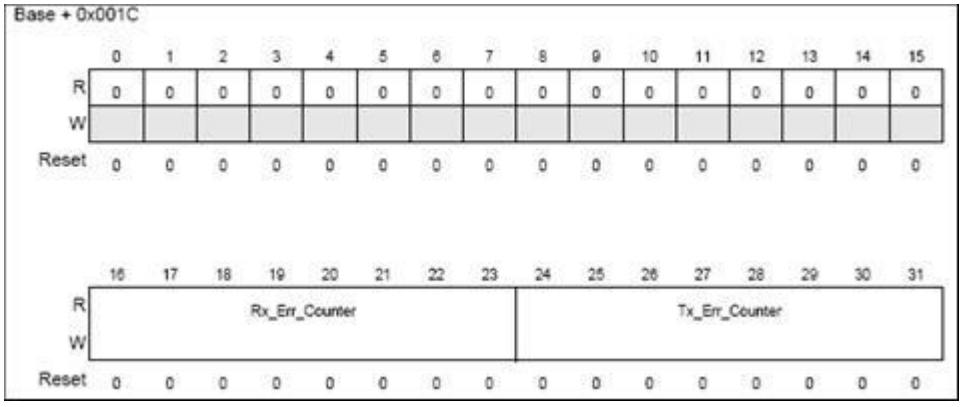
The module can generate up from Message Buffers and 4 interrupts due to Bus Off, Error, Tx Warning and Rx Warning. Eight interrupt vectors are associated to a FlexCAN module.
The 4 types of interrupt can be enabled globally in CR register, with the bits BOFFMSK, ERRMSK, TWRNMSK, RWRNMSK for Bus Off, Error, Tx and Rx Warning respectively. The flags associated to these interrupts are in ESR register.
Moreover, each one of the Message Buffers can be an interrupt source when valid message are transmitted or received, if its corresponding IMRH (Buffer 63 to 32) and IMRL (Buffer 31 to 0) bit is set. There is no distinction between Tx and Rx interrupts for a particular buffer, under the assumption that the buffer is initialized for either transmission or reception. Each of the buffers has assigned a flag bit in the IFRH (Buffer 63 to 32) and IFRL (Buffer 31 to 0) registers. The bit is set when the corresponding buffer completes a successful

transmission/reception and is cleared when the CPU writes it to '1' (unless another interrupt is generated at the same time).
The following table sums up the number of vector interrupt associated to the interrupt sources of the three FlexCAN modules of the MCU.

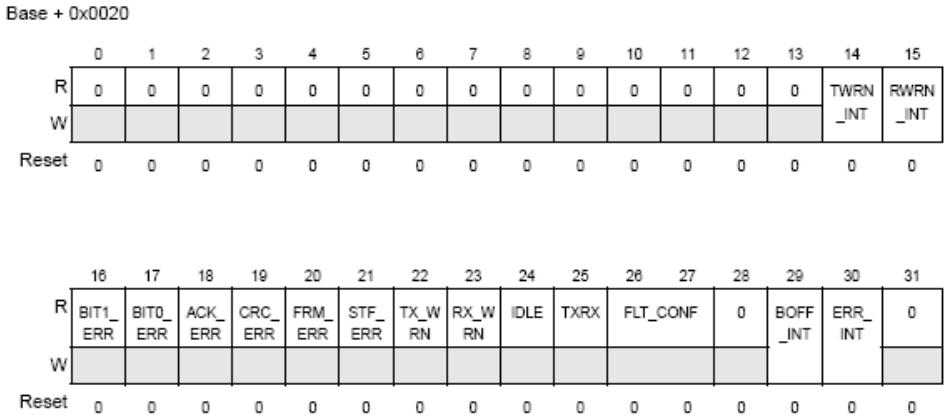
Vector number	Interrupt	Module
65	FlexCAN_ESR (Err_Int)	FlexCAN_0
66	FlexCAN_ESR_Bus_off, FlexCAN_TX_Warning, FlexCAN_RX_Warning	
68	FlexCAN_BUFF_00-03	
69	FlexCAN_BUFF_04-07	
70	FlexCAN_BUFF_08_11	
71	FlexCAN_BUFF_12_15	
72	FlexCAN_BUFF_16_31	
73	FlexCAN_BUFF_32-63	
85	FlexCAN_ESR (Err_Int)	FlexCAN_1
86	FlexCAN_ESR_Bus_off, FlexCAN_TX_Warning, FlexCAN_RX_Warning	
88	FlexCAN_BUFF_00-03	
89	FlexCAN_BUFF_04-07	
90	FlexCAN_BUFF_08_11	
91	FlexCAN_BUFF_12_15	
92	FlexCAN_BUFF_16_31	
93	FlexCAN_BUFF_32-63	
105	FlexCAN_ESR (Err_Int)	FlexCAN_2
106	FlexCAN_ESR_Bus_off, FlexCAN_TX_Warning, FlexCAN_RX_Warning	
108	FlexCAN_BUFF_00-03	
109	FlexCAN_BUFF_04-07	
110	FlexCAN_BUFF_08_11	
111	FlexCAN_BUFF_12_15	
112	FlexCAN_BUFF_16_31	
113	FlexCAN_BUFF_32-63	

g. Configuration of error management

Transmission or reception errors can occur in CAN bus and an error management strategy is defined by CAN protocol. This strategy relies on two 8 bit error counters: one for transmission errors, the second for reception errors. The FlexCAN module proposes the register ECR that concatenates Rx and Tx error counters. Each time an error is detected, one of this counter is incremented automatically (when the CAN bus is not in Freeze mode). If no errors are detected, the counters decrement regularly. Depending on the value of the counters, the module can be in error passive, error active or Bus-off Mode. The module enters in Bus-off mode when the counters reach 255. In that case, the FlexCAN stops transmitting and waits for 128 valid occurrences of 11 consecutive recessive bits.



The error conditions and the general status of the error counters are given by the register ESR.



h. Configuration of operation modes

The FlexCAN module has 4 functional modes:

- Normal mode (user or supervisor): the module is active, it receives or sends messages normally, and the entire CAN protocol functions are activated.
- Freeze mode: in this mode, no transmission or reception processes are allowed. The module loses synchronization with the CAN bus. If FRZ bit sets, the module enters in Freeze mode if HALT bit in MCR register is set or in debug mode.
- Listen-only mode: the transmission is disabled, the module only receives messages acknowledged by other CAN station. The module enters in this mode if the bit LOM in MCR register is set.
- Loop-back mode: an internal loop back between the transmitter output and the receiver input is done for test purpose. The RX CAN input is ignored and the TX CAN output is set to recessive mode. The module enters in this mode if bit LPB in MCR register is set.

And a low power mode:

- Disable mode: All the clocks are switched off. The module enters in this mode if bit MDIS in MCR register is set, only if all current transmission or reception processes have finished.

i. Transmission process

To ensure the transmission of a CAN frame, the CPU must prepare a Message Buffer by following this procedure:

- If the MB is active (transmission pending), the ABORT code (‘1001’) must be written in Code field of MCR register. Then read back the Code field and the IFLAG register to check if the transmission was aborted.
- Write the ID
- Write the data bytes
- Write the Length, Control and Code fields of the Control and Status word to activate the MB

Once the Message Buffer is activated, it will participate into the arbitration process and finally be transmitted according to its priority. At the end of the successful transmission, the Code field in the Control and Status word is updated, a status flag is set in the Interrupt Flag Register and an interrupt is generated if allowed by the corresponding Interrupt Mask Register bit.
If the Abort feature is enabled (bit AEN in MCR register), after the interrupt flag arises for a transmitting message buffer, the message buffer is blocked until the interrupt flag is negated by the CPU.
The arbitration process needs to be explained. It is an algorithm that scans all the Message Buffer memory to find the highest priority message to be transmitted. Depending on LBUF and LPRIO_EN bits on the Control Register, the priority depends on the lowest ID, the lowest Message Buffer number or the highest priority field. Chapter 22.4.4 gives details about arbitration process.
Once the highest priority Message Buffer is selected, the message is transferred in a temporary storage space called Serial Message Buffer (SMB). When a transmission opportunity is detected on the CAN bus, the message contained in the SMB is transmitted according to the CAN protocol specifications.

j. Reception process

To be able to receive CAN frames into the mailbox Message Buffers, the CPU must prepare one or more Message Buffers for reception by executing the following steps:

- If the Message Buffer has a pending transmission, write an ABORT code (‘1001’) to the Code field of the MCR register to request stop the transmission. Then read back the Code field and the IFLAG register to check if the transmission was aborted.
- If the MB is already programmed as a receiver, write ‘0000’ to the Code field of the Control and Status word to keep the Message Buffer inactive.
- Write the ID.
- Write ‘0100’ to the Code field of the MCR register to activate the Message Buffer.

A Message Buffer is free to receive a new frame if the Message Buffer is not locked, and if the Code field is either EMPTY, or FULL or OVERRUN but the CPU has already serviced the Message Buffer.

At the end of the previous step, the Message Buffer will be able to receive frames that match the programmed ID. At the end of a successful reception, the Message Buffer is updated by the Message Buffer Management as follows:

- The received ID, Data (8 bytes at most) and Length fields are stored.
- The Code field in the MCR register is updated.
- A status flag is set in the Interrupt Flag Register and an interrupt is generated if allowed by the corresponding Interrupt Mask Register bit.

When an interrupt arises after reception, the CPU must:
- Read the Control and Status word
- Read the ID buffer
- Read the data field

The reception process with the FIFO is not detailed in this document. Refer to chapter 22.4.5 of the reference manual of the MCU for the reception procedure with FIFO.

How works the matching process? The matching process is an algorithm executed by the MBM that scans the Message Buffer memory looking for reception Message Buffers programmed with the same ID as the one received from the CAN bus. When a frame is received, it is temporarily stored in a hidden auxiliary Message Buffer called Serial Message Buffer (SMB). The matching process takes place during the CRC field of the received frame. If a matching ID is found in one of the regular Message Buffers, the contents of the SMB will be transferred to the matched MB, except if any protocol error is detected.

If a valid message is received and if its ID is the same than the ID of several Message Buffers, the free Message Buffer with the lowest number will receive the message. If all the Message Buffers with the correct IDs are not free, the last matched Message Buffer is overwritten. The OVERRUN indication is written in the Code field.

k. Reception acceptance mask

The previous part details the matching process when a valid message is received. This process consists in finding a Message Buffer with a valid ID. It is possible to filter some Message Buffer with acceptance filter. The register 64 bit RXIMR provides individual masking for every 64 Message Buffers, only if BCC bit is set in MCR register. The RXIMR register can be configured only in Freeze mode.
The FlexCAN supports another masking process based on RGXMASK, RX14MASK and RX15MASK registers, if the BCC bit of MCR register is reset. This global reception mode is not described in this document.

5. Implementation of the CAN bus on the starter kit TRK-MPC5604B

The starter kit TRK-MPC5604B provides one SubD9 connector (JP3) to connect to a CAN bus. This connector is routed to CANH and CANL pins of the System Basis Chip (SBC) MCZ3390S5EK of the test board, called MCZ33905S5EK (U2). This component dedicated to the power management and embeds also a high-speed CAN transceiver. The RX and TX pins of this component are connected to the pins PC10 and PC11 of the MCU. PC10 is associated to CAN1TX (alternate function AF1), while PC11 can be associated to either CAN1RX or CAN4RX (the selection is done through the register PSMI (see SIUL)).
The CAN transceiver ensures the interface between the CAN controller and the CAN bus. The CAN transceiver is embedded within the SBC MCZ33905. The CAN of the SBC will work correctly in two situations: either if the SBC is forced in its own debug mode, or if the internal watchdog of the SBC is refreshed periodically. In this document, we will detail only the method to force the SBC in debug mode. Refer to the SBC datasheet for more information

about the refresh operation of its watchdog. Several steps must be done to ensure the entry of SBC in debug mode:

- The SBC must be supplied under 12 V to activate the on-chip voltage regulator of the CAN transceiver. On the starter kit TRK-MPC5604B, the power supply must be provided by an external 12 V source and by placing the jumper J1 in 5-6 position. You should verify that the pin 16 – DBG of the SBC (you can also probe that pin on the test point TP1) is between 8 – 10 V, that the pin 22 – RST is at 5 V, and the pin 6 – 5VCAN is at 5 V (it proves that the CAN on-chip voltage regulator operates correctly).

- The SBC will be used in Debug mode. In Debug mode, the CAN transceiver remains always active. To force the component to enter in this mode, the MCU must configure the SBC by sending the appropriate SPI commands. On the starter kit TRK-MPC5604B, the module DSPI1 pins (port H) are connected to the SBC.

You can follow the procedures below to send the correct SPI command to the SBC:

```
void initDSPI_1(void) {
  DSPI_1.MCR.R = 0x80010001;
  DSPI_1.CTAR[0].R = 0x78024424;

  DSPI_1.MCR.B.HALT = 0x0;            /* Exit HALT mode: go from STOPPED to RUNNING
state*/
  SIU.PCR[113].R = 0x0A04;          /* MPC56xxB: Config pad as DSPI_0 SOUT output -
PH1*/
  SIU.PCR[112].R = 0x0103;        /* MPC56xxB: Config pad as DSPI_0 SIN input - PH0 */
  SIU.PSMI[8].R = 2;            /* MPC56xxB: Select PCR 112 for DSPI_1 SIN input */

  SIU.PCR[114].R = 0x0A04;        /* MPC56xxB: Config pad as DSPI_0 SCK output - PH2 */
  SIU.PCR[115].R = 0x0A04;         /* MPC56xxB: Config pad as DSPI_0 PCS0 output - PH3
*/
}

void ReadDataDSPI_1(void) {
  uint16_t RecDataMaster = 0;          /* Data received on master SPI */
  while (DSPI_1.SR.B.RFDF != 1){}  /* Wait for Receive FIFO Drain Flag = 1 */
  RecDataMaster = DSPI_1.POPR.R;    /* Read data received by slave SPI */
  DSPI_1.SR.R = 0x80020000;        /* Clear TCF, RDRF flags by writing 1 to them */
}

void Init_SBC_DBG(void)
{
        vuint32_t i;
        vuint32_t j = 0;
        DSPI_1.PUSHR.R = 0x0001DF80;   /* Read Vreg register H, clear power on flags*/
         ReadDataDSPI_1();
        for (i=0; i<200; i++) {
        j=j+1;
        }
```

```
        j = 0;
        DSPI_1.PUSHR.R = 0x00015A00;  /* Go into 'Normal Mode'*/
         ReadDataDSPI_1();
        for (i=0; i<200; i++) {
        j=j+1;
        }

        j = 0;
        DSPI_1.PUSHR.R = 0x00015E90;  /*Configure voltage regulator*/
        ReadDataDSPI_1();
        for (i=0; i<200; i++) {
        j=j+1;
        }

        j = 0;
        DSPI_1.PUSHR.R = 0x000160C0;  /* Activate CAN transceiver for TX/RX*/
        ReadDataDSPI_1();
        for (i=0; i<200; i++) {
        j=j+1;
        }
}
```

XIV - SPI bus and DSPI module

This chapter aims at providing some elements about hardware architecture and operation principles of SPI bus, but also the more basic programming elements for the embedded SPI controller of the MPC5604B. Refer to Chapter 20 – Deserial Serial Peripheral Interface for the configuration of DSPI module.

1. Some elements about SPI protocol

The SPI is a synchronous serial communication bus which operates in full-duplex mode. The communication is based on a master-slave protocol. Several slaves can be placed on the bus, the selection is done through a Chip Select line.
The bus is made of 4 logical signals:

- SCLK: the clock generated by the master
- MOSI (Master Output, Slave Input) or Data Out: data sent by the master
- MISO (Master Input, Slave Output) or Data In: data sent by the slave
- CS (Chip Select): selection of the slave by the master, usually active at low state

The MOSI of the master must be connected to the MISO of the slave and vice-versa. At each SCLK period, one bit is exchanged. When a data transfer operation is performed, data is serially shifted by a pre-determined number of bit positions. Because the registers are linked, data is exchanged between the master and the slave. The data that was in the master's shift register is now in the shift register of the slave, and vice versa. The number of bit to exchange can vary (it must not exceed the size of shift register).

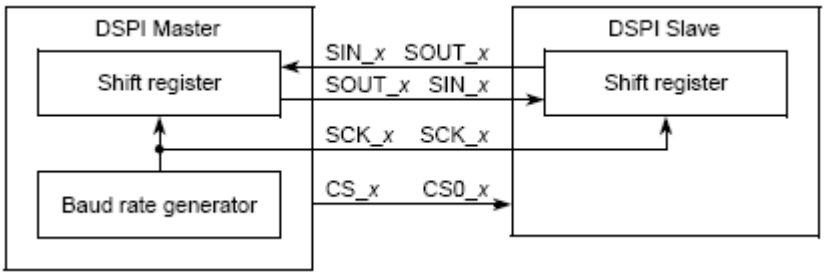


Figure 19 – SPI protocol overview (Bolero512K_RM_Rev7_07_2010.pdf - p. 522)

2. Presentation of DSPI module

a. General description

The MCU embeds 3 DSPI modules called DSPI_0, DSPI_1, DSPI_2, with 6 clock and attribute registers and 6 Chip Select per module. Each DSPI module x has the following pins:

- CS0_x: peripheral chip select 0 (slave select in master mode)
- CS1_x to CS3_x: peripheral chip select 1 to 3 (unused in slave mode)
- CS4_x: peripheral chip select 4 (master trigger)
- CS5_: peripheral chip select 5 (unused in slave mode. In master mode, it is used as a strobe signal transmitted after CSx signal to prevent from glitches)
- SIN_x: serial data in
- SOUT_x: serial data out
- SCK_x: serial clock

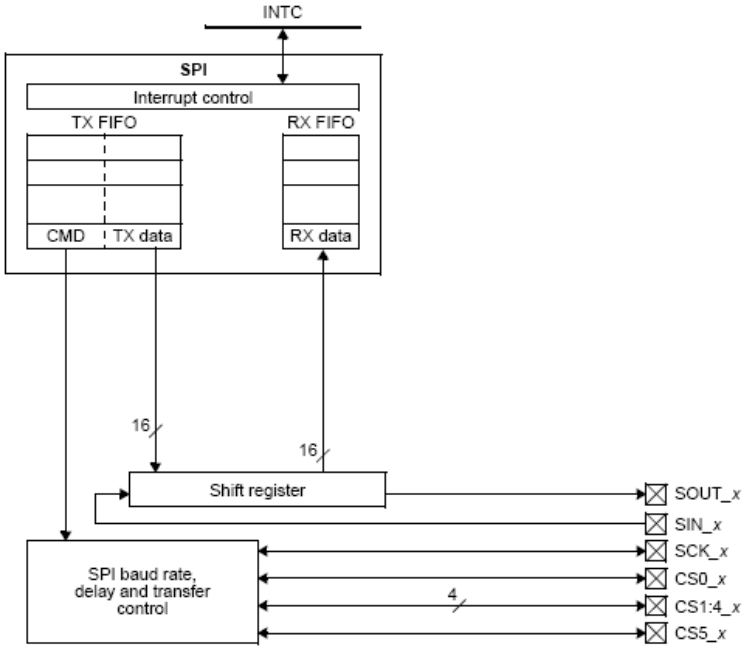


Figure 20 - Block diagram of DSPI module (Bolero512K_RM_Rev7_07_2010.pdf - p. 495)

A 16 bit shift register in master and a 16 bit shift register in slave are associated to SOUT_x, and SIN_x signals, and form a 32 bit register.
The SPI frames can be from 4 to 16 bits long. The data to be transmitted can come from queues stored in SRAM external to the DSPI. Host software can transfer the SPI data from the

queues to a first-in first-out (FIFO) buffer. Host software can add (or push) entries to the TX FIFO by writing to the DSPI*x*_PUSHR. The DSPI ignores attempts to push data to a full TX FIFO.
The received data is stored in entries in the receive FIFO (RX FIFO) buffer. Host software transfers the received data from the RX FIFO to memory external to the DSPI.

The DSPI has 4 modes of operation:

- Master mode (DSPI initiates and control the serial communication, the pins SCK, Sout and CS are outputs and controlled by DSPI)
- Slave mode (DSPI responds to external SPI bus masters and cannot initiate communications. The SCK and CS pin are configured as input, an internal pull-up must be configured on CS0_x input. All transfer attributes are controlled by the bus master, except the clock polarity, clock phase and the number of bits to transfer which must be configured in the DSPI slave to communicate correctly.)
- Module disable mode (low power mode)
- Debug mode

The DSPI has two operating states: STOPPED and RUNNING. The states are independent of DSPI configuration. The default state of the DSPI is STOPPED. In the STOPPED state no serial transfers are initiated in master mode and no transfers are responded to in slave mode. The STOPPED state is also a safe state for writing the various configuration registers of the DSPI without causing undetermined results. After a reset, the DSPI module is in STOPPED state.

b. TX Buffering and transmitting mechanisms

The data field in the executing TX FIFO entry is loaded into the shift register and shifted out on the serial out (SOUT_x) pin. The TX FIFO functions as a buffer of SPI data and SPI commands for transmission. SPI commands and data are added to the TX FIFO by writing to the DSPI push TX FIFO register (DSPIx_PUSHR). TX FIFO entries can only be removed from the TX FIFO by being shifted out or by flushing the TX FIFO. The TX FIFO counter field (TXCTR) in the DSPI status register (DSPIx_SR) indicates the number of valid entries in the TX FIFO. The TXCTR is updated every time the DSPI _PUSHR is written or SPI data is transferred into the shift register from the TX FIFO.

The TX FIFO entries are removed (drained) by shifting SPI data out through the shift register. Entries are transferred from the TX FIFO to the shift register and shifted out as long as there are valid entries in the TX FIFO. Every time an entry is transferred from the TX FIFO to the shift register, the TX FIFO counter is decremented by one. At the end of a transfer, the TCF bit in the DSPIx_SR is set to indicate the completion of a transfer. The TX FIFO is flushed by writing a ‘1’ to the CLR_TXF bit in DSPIx_MCR. If an external SPI bus master initiates a transfer with a DSPI slave while the slave’s DSPI TX FIFO is empty, the transmit FIFO underflow flag (TFUF) in the slave’s DSPIx_SR is set.

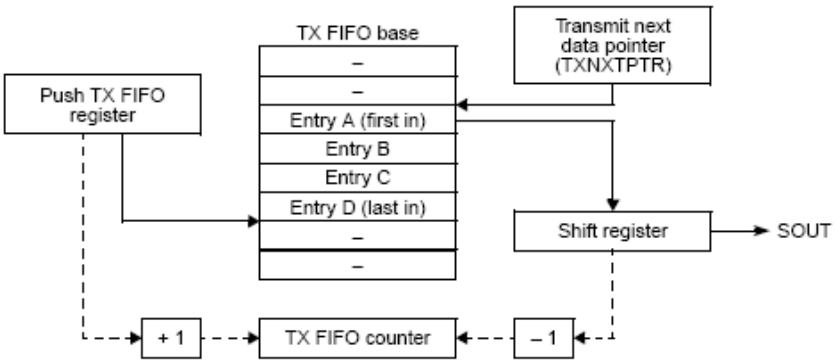


Figure 21 – Structure of the TX FIFO and associated counter (Bolero512K_RM_Rev7_07_2010.pdf - p. 545)

c. RX buffering and receiving mechanisms

The RX FIFO functions as a buffer for data received on the SIN pin. The RX FIFO holds four received SPI data frames. SPI data is added to the RX FIFO at the completion of a transfer when the received data in the shift register is transferred into the RX FIFO. SPI data is removed (or popped) from the RX FIFO by reading the DSPIx_POPR register. RX FIFO entries can only be removed from the RX FIFO by reading the DSPIx_POPR or by flushing the RX FIFO. The RX FIFO counter field (RXCTR) in the DSPI status register (DSPIx_SR) indicates the number of valid entries in the RX FIFO. The RXCTR is updated every time the DSPI _POPR is read or SPI data is copied from the shift register to the RX FIFO.

The RX FIFO is filled with the received SPI data from the shift register. While the RX FIFO is not full, SPI frames from the shift register are transferred to the RX FIFO. Every time an SPI frame is transferred to the RX FIFO, the RX FIFO counter is incremented by one. If the RX FIFO and shift register are full and a transfer is initiated, the RFOF bit in the DSPIx_SR is set indicating an overflow condition. Depending on the state of the ROOE bit in the DSPIx_MCR, the data from the transfer that generated the overflow is ignored or put in the shift register. If the ROOE bit is set, the incoming data is put in the shift register. If the ROOE bit is cleared, the incoming data is ignored.

Host software can remove (pop) entries from the RX FIFO by reading the DSPIx_POPR. A read of the DSPIx_POPR decrements the RX FIFO counter by one. Attempts to pop data from an empty RX FIFO are ignored, the RX FIFO counter remains unchanged. The data returned from reading an empty RX FIFO is undetermined.

d. Transfer attributes

The transfer attributes define the baud rate, the clock polarity, the delays between clock edge and CS and data sampling… In master mode, they define SCK signal properties. In Slave mode, the transfer attributes of DSPI must be the same than the Master transfer attribute to ensure a correct reception.

The DSPI module contains 6 CTAR register which defines the transfer attributes. The SPI slave mode transfer attributes are set in the DSPIx_CTAR0.

The SCK_x frequency and the delay values for serial transfer are generated by dividing the system clock frequency by a prescaler and a scaler with the option of doubling the baud rate. The baud rate is the frequency of the serial communication clock (SCK_x). The system clock is divided by a baud rate prescaler (defined by DSPIx_CTAR[PBR]) and baud rate scaler (defined by DSPIx_CTAR[BR]) to produce SCK_x with the possibility of doubling the baud

rate. The DBR, PBR, and BR fields in the DSPIx_CTARs select the frequency of SCK_x using the following formula:

$$\text{SCK baud rate} = \frac{f_{SYS}}{\text{PBRPrescalerValue}} \times \frac{1 + \text{DBR}}{\text{BRScalerValue}}$$

The CS_*x* to SCK_*x* delay is the length of time from assertion of the CS_*x* signal to the first SCK_*x* edge.

$$t_{CSC} = \frac{1}{f_{SYS}} \times \text{PCSSCK} \times \text{CSSCK}$$

The after SCK_*x* delay is the length of time between the last edge of SCK_*x* and the negation of CS_*x*.

$$t_{ASC} = \frac{1}{f_{SYS}} \times \text{PASC} \times \text{ASC}$$

The delay after transfer is the length of time between negation of the CS*x* signal for a frame and the assertion of the CS*x* signal for the next frame.

$$t_{DT} = \frac{1}{f_{SYS}} \times \text{PDT} \times \text{DT}$$

When the DSPI is the bus master, the CPOL and CPHA bits in the DSPI clock and transfer attribute registers (DSPIx_CTARn) select the polarity and phase of the serial clock, SCK_x. The polarity bit selects the idle state of the SCK_x. The clock phase bit selects if the data on SOUT_*x* is valid before or on the first SCK_x edge. In slave mode, clock polarity, clock phase and number of bits to transfer must be identical for the master device and the slave device to ensure proper transmission.
See 20.8.5 chapter for schematic of SPI transfer for different clock polarity.

e. Interrupts

The DSPI has five conditions that can generate interrupt requests:

- End of transfer queue has been reached (flag EOQF): it indicates that the end of a transmit queue is reached. The end of queue request is generated when the EOQ bit in the executing SPI command is asserted and the EOQF_RE bit in the DSPIx_RSER is set.

- Current frame transfer is complete (flag TCF): it indicates the end of the transfer of a serial frame. The transfer complete request is generated at the end of each frame transfer when the TCF_RE bit is set in the DSPIx_RSER.

- TX FIFO underflow has occurred (flag TFUF): it indicates that an underflow condition in the TX FIFO has occurred. If an external SPI bus master initiates a transfer with a DSPI slave while the slave's DSPI TX FIFO is empty, the transmit FIFO underflow flag (TFUF) in the slave's DSPIx_SR is set. If the TFUF bit is set while the TFUF_RE bit in the DSPIx_RSER is set, an interrupt request is generated.

- RX FIFO overflow has occurred (flag RFOF): it indicates that an overflow condition in the RX FIFO has occurred. A receive FIFO overflow request is generated when RX FIFO and shift register are full and a transfer is initiated. The RFOF_RE bit in the DSPIx_RSER must be set for the interrupt request to be generated. Depending on the state of the ROOE bit in the DSPIx_MCR, the data from the transfer that generated the overflow is either ignored or shifted in to the shift register. If the ROOE bit is set, the

incoming data is shifted in to the shift register. If the ROOE bit is negated, the incoming data is ignored.

- FIFO overrun has occurred (flag TFUF or RFOF): it indicates that at least one of the FIFOs in the DSPI has exceeded its capacity. The FIFO overrun request is generated by logically OR'ing together the RX FIFO overflow and TX FIFO underflow signals.

3. Configuration of the DSPI module

a. Module configuration

The module configuration is ensured by the DSPIx_MCR register.

Address: Base + 0x0000 Access: R/W

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	MSTR	CONT_SCKE	DCONF[ ]		FRZ	MTFE	PCSSE	ROOE	0	0	PCSIS 5	PCSIS 4	PCSIS 3	PCSIS 2	PCSIS 1	PCSIS 0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	MDIS	DIS_TXF	DIS_RXF	CLR_TXF	CLR_RXF	SMPL_PT[ ]		0	0	0	0	0	0	0	HALT
W																
Reset	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1

The bit MSTR configures the module in Master ('1') or Slave ('0') mode. The MDIS bit allows the module disable mode entry. The FRZ bit stops SPI transfer when the device enters in debug mode. The bit HALT provides a mechanism for software to start ('0') and stop ('1') DSPI transfer: transition from STOPPED to RUNNING mode. The bits DIS_TXF and DIS_RXF disable RX and TX FIFO. The bits CLR_TXF and CLR_RXF clear or flush the TX or RX FIFO by clearing the associated counter. See MCU datasheet for details about the other bits.

b. Clock and transfer attributes

The DSPI modules each contain six clock and transfer attribute registers (DSPI*x*_CTAR*n*) which are used to define different transfer attribute configurations. Each DSPI*x*_CTAR controls the frame size, the Baud rate and transfer delay values, the clock phase and polarity and defines if MSB or LSB is considered as first bit. Do not write in this register in RUNNING mode (HALT = 0).
In slave mode, DSPIx_CTAR0 is used to set the slave transfer attributes. When the DSPI is configured as an SPI master, the CTAS field in the command portion of the TX FIFO entry selects which of the DSPIx_CTAR registers is used on a per-frame basis.

Address:
Base + 0x000C (DSPIx_CTAR0)
Base + 0x0010 (DSPIx_CTAR1)
Base + 0x0014 (DSPIx_CTAR2)
Base + 0x0018 (DSPIx_CTAR3)
Base + 0x001C (DSPIx_CTAR4)
Base + 0x0020 (DSPIx_CTAR5)

Access: R/W

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R/W	DBR	FMSZ[]				CPOL	CPHA	LSBFE	PCSSCK[]		PASC[]		PDT[]		PBR[]	
Reset	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R/W	CSSCK[]				ASC[]				DT[]				BR[]			
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The field FMSZ defines the frame size (from 4 to 16). CPOL bit defines the clock polarity, i.e. the inactive state of SCLK. CPHA defines the clock phase, i.e. which SCK edge causes the data to change or to be captured. The bit LSBFE defines if the LSB or MSB is transferred first. The baud rate depends on DBR, PBR and BR bit fields (see datasheet for more information about computation of bit rate). Depending on DBR, PBR and CPHA, duty cycle of SCLK is changed (see Table 20-6).
The fields PCSSCK, PASC, PDT, CSSCK, ASC and DT define different delays between either SCK, CS and data.

c. TX FIFO writing

Data are written by software in TX FIFO by the DSPIx_PUSHR register. Data written in this register are written in TX FIFO. This register contains command bits and data (16 bits). The field CTAS defines which CTAR register is used for clock and transfer attributes. The bit PCSx defines if signal CSx is asserted during transfer.

Address: Base + 0x0034

Access: R/W

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R/W	CONT	CTAS[]			EOQ	CTCNT	0	0	0	0	PCS 5	PCS 4	PCS 3	PCS 2	PCS 1	PCS 0
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R/W	TXDATA[]															
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The data in TX FIFO are visible in registers DSPIx_TXFRn (n from 0 to 3). They are read-only registers and cannot be modified.

d. RX FIFO writing

Received data can be read by software in TX FIFO by the DSPIx_POPR register. This register contains only received data (16 bits). Once the RX FIFO is read, the read data pointer is moved to the next entry in the RX FIFO. Therefore, read DSPIx_POPR only when you need the data.

Address: Base + 0x0038 Access: R/O

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	RXDATA[ ]															
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The data in RX FIFO are visible in registers DSPIx_RXFRn (n from 0 to 3). They are read-only registers and cannot be modified.

e. Interrupt configuration and status

The DSPI*x*_RSER enables flag bits (see part 2.e of this chapter for details bout these flags) in the DSPI*x*_SR to generate interrupt requests. Do not write to the DSPI*x*_RSER while the DSPI is running.

Address: Base + 0x0030 Access: R/W

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	TCF_RE	0	0	EOQF_RE	TFUF_RE	0	TFFF_RE	TFFF_DIRS	0	0	0	0	RFOF_RE	0	RFDF_RE	RFDF_DIRS
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The status of the module is indicated by flag bits in status register DSPIx_SR. They are set by hardware and reflect the state of DSPI module. They can be cleared by software only by writing ‘1’.

Address: Base + 0x002C Access: R/W

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	TCF	TXRXS	0	EOQF	TFUF	0	TFFF	0	0	0	0	0	RFOF	0	RFDF	0
W	w1c			w1c	w1c		w1c						w1c		w1c	
Reset	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	TXCTR[ ]				TXNXTPTR[ ]				RXCTR[ ]				POPNXTPTR[ ]			
W																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TCF flag indicates that a transfer is completed, i.e. all bits in a frame have been shifted out. EOQF flag indicates that the last entry in queue transmission is ongoing. The flag TFFF indicates that the TX FIFO is not full and be filled. It is cleared by software or when the FIFO is full.

RFDF flag indicates the the RX FIFO is not empty and the received data can be drained in DSPIx_POPR register. The flags TFUF and RFOF reflect TX FIFO underflow and RX FIFO overflow conditions.

The bit TXRXS indicates that TX and RX operation are enabled (RUNNING state) or disabled (STOPPED mode). TXCTR and RXCTR are TX and RX FIFO counter.

TXNXTPTR indicates which entry in TX FIFO will be transmitted during the next transfer. POPNXTPTR contains a pointer to the RX FIFO entry that is returned when the DSPIx_POPR is read. The POPNXTPTR is updated when the DSPIx_POPR is read.